

UNIVERSITY OF KWAZULU-NATAL

**VOLTAGE UNBALANCE EMISSION LIMITS FOR NEW
CONNECTIONS INCLUDING SINGLE PHASE MV
SYSTEMS**

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2011

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Abstract

Voltage unbalance performance of a power line depends on a few parameters that are not necessarily constant at any given instance. The random nature of a power system raises questions around the ability of a system planner to allocate equitable share of the power quality parameters, like voltage unbalance, at design stage. Even a more interesting question is whether applying current methods will guarantee that emissions will be under the set limits. The presence of single or dual phase feeders on such a line will result in a more dynamic voltage unbalance.

The first part of this research is a study on deterministic method of voltage unbalance allocation presented by the IEC. The IEC 61000-13-3 report is a comprehensive guideline and the best place to start when looking to develop an emissions standard for voltage unbalance. This dissertation presents a method that can be used to set planning levels for unbalance emission at various voltage levels in order to avoid high voltage unbalance at the end user. The method depends on the agreed power of the customer, the power of the unbalanced load, and the system characteristics. The method works well for short feeders with roughly the same negative sequence impedance and equal short circuit levels. In South Africa, however, there are radial feeders that span over 100km. Hence on such a feeder, there can be ratios of 1:10 between sending end and the last customer on the line. Preliminary research revealed that IEC 61000-6-3, a report on allocation of harmonics, has a method applicable to long feeders. This method was investigated extensively and applied to voltage unbalance allocation. At the core of the method is the assumption that feeders have an even distribution of load. To illustrate the application of this method an example is given.

The second part of the study explores a stochastic method of voltage unbalance allocation. In this study the possibility of random connection is considered. A Monte Carlo study is presented. The impact of various parameters are analysed and the findings reveal that phase allocation has the most influence on emission. The results show that the method of random connection of loads can be applied in special conditions only i.e. where sizes of loads do not differ greatly and the number of required connections are low.

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Abbreviations

ANSI – American National Standards Institute

ASD – Adjustable Speed Drives

EAF – Electric Arc Furnace

EHV – Extra-High Voltage

EMC – Electromagnetic Compatibility

EPRI – Electrical Power Research Institute

HV – High Voltage

IEC – International Electrotechnical Commission

LV – Low Voltage

MV – Medium Voltage

NEMA – National Electrical Manufacturers Association

NERSA – National Electricity Regulator of South Africa

OLE – Object Linking and Embedding

PCC – Point of Common Coupling

POC – Point of connection

SVC – Static VAR Compensator

SWER – Single-Wire Earth Return

UPS – Uninterruptible Power Supply

VA – Voltage Amp

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CHAPTER 1 INTRODUCTION

1.1 Introduction

In an ideal power system design all the loads are balanced three phase loads. However, it is a known fact that the distribution of power is mainly done with single-phase loads. The net effect of this is voltage unbalance on three-phase systems. Unbalanced voltages can have adverse effects on equipment and the electric distribution system according to von Jouanne and Banerjee[1]. Unlike other voltage disturbances in power systems, for which the effect is evident to the customer, voltage unbalance is a disturbance which the effects are produced in the long run [2]. Voltage unbalance on the power system will cause what is referred to as technical losses on the system. Equipment like induction motors, adjustable speed drives and convertors will show signs of overheating at the presence of voltage unbalance. According to Lakervi and Holmes [3], unbalance load conditions can arise on MV rural systems where single-phase distribution transformers and spur-line supplies are tapped off the 3-phase network. Single phase rural distributions systems like SWER and dual-phase have long distribution lines. Voltage unbalance is also high in large urban power systems where heavy single phase lighting loads, are required for commercial facilities. Single phase railway traction loads are also a major contributor to voltage unbalance in urban areas. However, proper steps can be taken at design phase to minimise unbalance[1].

In most utilities new connections are allocated emission levels as part of conditions of service. It is therefore necessary for the utility to know upfront what each customer should be allocated before they are granted permission to connect to the system. This should be in line with their network development plan. This poses a challenge to system design engineers to answer the following questions:

- What is the current voltage unbalance emission on the system?
- Is there room for further emissions to be allowed on the system?
- What should be allocated to future connections?

It is therefore necessary to predict what the new users will contribute the already existing emissions.

IEC, an international standards body, has compiled a technical report (IEC 61000-3-13 [4]) that tackles the dynamics of planning for unbalance loads on to the system. The work is done under

the auspices of study committee 77A. IEC presents guideline principles that can be used for coordinated allocation of system capacity to absorb voltage unbalance disturbance. The report emphasises the use of statistical methods to estimated current and future unbalance in place of conventional deterministic methods.

1.2 Definition of research problem and research questions

1.2.1 Problem definition

1.2.1.1 Voltage unbalance allocation on long feeders

The IEC 61000-13-3 report is a comprehensive guideline and the best place to start when looking to develop an emissions standard for voltage unbalance. The report presents a method that can be used to set planning levels for unbalance emission at various voltage levels in order to avoid high voltage unbalance at the end user.

The proposed approach for setting emission limits for unbalanced installations, according to IEC 61000-13-3, depends on the agreed power of the customer, the power of the unbalanced-load equipment, and the system characteristics. It is important to also consider, in the case of voltage unbalance, the fact that the power system itself can also contribute to voltage asymmetries (e.g. untransposed, non-perfectly transposed lines, and lines in parallel rights of way), so the share of emissions should allow for an equitable share of emissions for the power system as a source of possible emissions too. The objective, as stated in IEC 61000-13-3[4], is to limit the injection from the total load of individual customer installations and the system's inherent sources of unbalance to levels that will not result in voltage unbalance levels that exceed the planning levels.

A global emission is determined per voltage level based on the statutory limits. The global limit is the total disturbance that customers are allowed to contribute at the specific voltage level. Individual customers are allocated a portion on the global emission. To ensure equitable share, a ratio of average agreed power with the customer and the total planned power $\frac{S_i}{S_t}$ [4]. Therefore

customers with equal agreed power will be allocated equal percentage of the global emission fulfilling the principle:

“MV customers of equal maximum demand along the same feeder should have equal unbalance allocation”.

The method works well for short feeders with roughly the same negative sequence impedance and equal short circuit levels. In South Africa, however, there are feeders that spurn long distances. Hence, on such a feeder there can be fault level ratios of 1:10 between sending end and the last customer on the line. Therefore, a method that makes provision for long feeders should be investigated.

Preliminary research revealed that IEC 61000-6-3 [5], a report on allocation of harmonics, has a method to deal with long feeders. Therefore the first part of this dissertation investigates the possibility of applying a similar method of harmonics allocation to voltage unbalance allocation.

1.2.1.2 Voltage unbalance and random SWER connections

The South African utility, Eskom, has a fair amount of radial systems into the rural areas. These feeders are generally long and some contain unbalanced MV spurs like SWER and Dual Phase. System planners are often posed with the challenge of keeping emission levels below set limits, while making provision for single or dual phase loads. The dynamics of balancing parameters is not an easy one, considering the fact that a lot of parameters used in calculations are random by nature. A few of these parameters are listed:

- large single phase loads;
- point of connection;
- phase selection; and
- line transposition.

The challenge of taking all these parameters into consideration can be tedious and since rural networks are not on the important network list of most utilities, most system designers would consider worst case scenarios and would disregard further details. Another view point is that the single phase loads should be connected randomly. The important question to then answer is; what is the probability that the unbalance emission will be within limit? The second part of this research attempts to answer this question.

1.2.2 Research questions

There are two main question this research attempts to answer:

- Can the new method used in IEC 61000-6-3[5] for harmonics along long feeders be applied to IEC 61000-13-3 for voltage unbalance?

- What is the effect on voltage unbalance if new single or dual phase connections were provisioned randomly?

1.2.3 Aim of the research

The aim of this research is to contribute to Eskom's planning strategy for voltage unbalance allocation along long feeders and random connection inherently unbalanced loads. .

1.2.2 Objectives of the research

The research conducted in this study is divided into two independent studies, which however, are both aimed at understanding voltage unbalance allocation. Hence this research has two primary objectives.

The first objective is to derive a proposal for dealing with allocation along long feeders. This research will also contribute to the ongoing dialog at IEC on this topic.

The second objective is to present results simulation proof on the effect of random connection of SWER loads.

1.3 Research hypothesis

The voltage unbalance allocation method proposed in IEC 61000-3-13 [4] can be modified in order to provide a solution for long feeders that will not exceed set emission limits.

Random connection of single phase MV loads (e.g. SWER) on a long three phase feeder will result in a voltage unbalance that will not exceed set emission limits.

1.4 Importance of study

Quality of supply has become an important aspect of power supply throughout the world. South African utilities like Eskom are under pressure to show improvement on their quality of supply. The National Energy Regulator of South Africa (NERSA) uses quality of supply indices to measure the overall performance of Eskom. Hence, issues related to quality of supply, like voltage unbalance, are important to investigate

SWER makes up a small portion of power distribution networks around the world and hence can be overlooked when setting international standards. There is renewed interest in SWER, particularly in developing African countries like Uganda. It is therefore important to investigate SWER technology and to continue to insist on international standards that cover SWER in their content.

1.5 Limitations

The study is limited to MV systems and does not include large LV single phase loads which also contribute significantly to voltage unbalance. The study evaluates the methods proposed in IEC 61000-3-13 [4] only and does not go beyond the scope of this report.

1.6 Research Methodology

1.6.1 Voltage unbalance limits on long feeders

This study entail a thorough analysis of emission limits methods proposed in IEC 61000-3-13 [4] for voltage unbalance and IEC 61000-3-6[5] for harmonics in relation to long feeders. The focus of the study would be to refine the harmonics method for application on unbalance. The study will follow the following steps:

- thorough study of the two IEC reports;
- study the proposal for long feeders;
- derive long feeder proposal for unbalance; and
- present a practical example of the proposed method.

Over and above the focus areas mentioned above will be to research the new statistical approach to emission summations and counter arguments found in literature. Included to the above, the study of current Eskom practice in setting emission limits, with emphasis on SWER.

1.6.2 Random connection of unbalanced loads and their impact on emission

This study evaluates the probability of not exceeding voltage unbalance limits while randomly connecting unbalanced loads to a radial feeder. Monte Carlo simulations are used to generate random variables followed by network simulation. The following steps will be followed:

- study the statistical methods for suitable for generating random scenarios (Monte-Carlo);
- Select variables to be studied;
- Study random characteristic of selected variables to assign suitable probability distribution function curve;

- Generate random scenarios;
- Select a network simulation tool;
- Design a network for the study;
- Simulation ; and
- Analysis of results.

1.7 Outline of chapters

Chapter 1: Introduction

This chapter will cover the following

- introduction of research problem;
- importance of the study;
- assumptions and limitations of the study; and
- a framework of the study.

Chapter 2: Literature review

This chapter introduces the concept of voltage unbalance and single phase loads in particular SWER. This chapter will also show details contained in IEC61000-3-13[4].

Chapter 3: Allocating unbalance emission limits on long feeders

The extent to which the method of allocating unbalance in IEC 61000-3-13 [4] are test for application on MV long feeders.

Chapter 4: Random connection of SWER and the effect on Voltage Unbalance

A method for random allocation of voltage unbalance to single phase MV loads like SWER are investigated.

- Statistical simulation
- Network Simulation

- Discussion of results

Chapter 5: Conclusions and recommendations

This chapter discusses conclusion drawn from the study and recommend possible research topics.

CHAPTER 2 LITERATURE REVIEW

2.1 Voltage unbalance

A balanced power supply system is characterised by equal line to neutral voltages and phase displacement of 120 degrees, according to [6]. This system is said to be symmetrical (balanced). Any deviation from the state of balance i.e. equal voltage magnitude and phase displacement, will result in asymmetrical voltage [6].

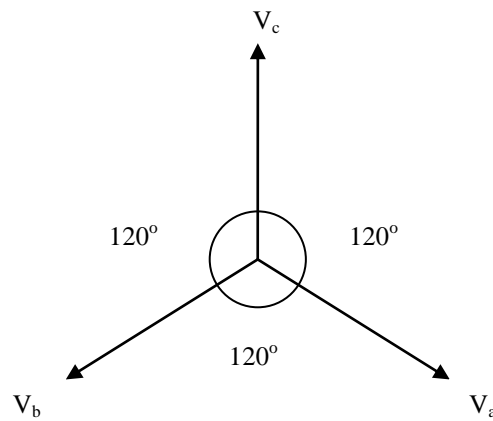


Figure 2-1: A balanced system

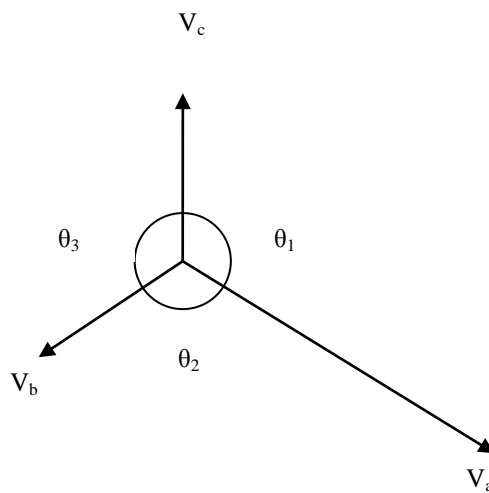


Figure 2-2: An unbalanced system

Voltage unbalance, in short, is caused by a condition of unbalanced phase impedances, or unbalanced loads, or a combination of both [3].

2.1.1 Definition of voltage unbalance

There are two ways in which voltage unbalance is defined in the available international standards. The first method, which is widely used in European standards (IEC), is defined in terms of symmetrical components. The second method is defined by ANSI/NEMA (National Electrical Manufacturers Association of USA) and is used predominantly by the Americans. The method expresses unbalance in terms of phase voltages. IEC definition of voltage unbalance factor (VUF) is the one most common [1]. South African standards mirror those of Europe, in particular IEC. Therefore the South African utilities also use the method of symmetrical components. Henceforth reference to voltage unbalance calculation will refer to the symmetrical components method of VUF.

The VUF method can be expressed in two ways, the first being negative sequence and the second referred to as zero sequence. The equations are given below:

$$\text{a) negative sequence voltage unbalance factor} = \frac{V_2}{V_1} \quad (2-1)$$

$$\text{b) zero sequence voltage unbalance factor} = \frac{V_0}{V_1} \quad (2-2)$$

(where V_1 , V_2 and V_0 are positive, negative and zero sequence voltages respectively). According to [6], a zero sequence currents cannot flow in three wire systems such as three-phase induction motors. Therefore zero sequence voltage unbalance has no significant value in analysing the impact of unbalance on the system [6]. What is, however, significant according to [6] is that negative sequence unbalance indicates the level of voltage that attempts to turn a three-phase induction motor in a direction opposite to that established by the positive sequence voltages. The negative sequence voltage unbalance can also be expressed simplistically by equation (2-3) which requires only the three line to line voltage readings, as stated in [6].

$$\frac{V_2}{V_1} = \sqrt{\frac{1 - \sqrt{3 - 6\beta}}{1 + \sqrt{3 - 6\beta}}} \quad (2-3)$$

$$\text{where } \beta = \frac{V_{ab}^4 + V_{bc}^4 + V_{ca}^4}{(V_{ab}^2 + V_{bc}^2 + V_{ca}^2)^2} \quad (2-4)$$

The NEMA standard definition is completely different to the IEC. Equation (2-5) gives the expression used to calculate unbalance.

$$VoltageUnbalance = \frac{\text{Maximum deviation of mean}\{V_{ab}, V_{bc}, V_{ca}\}}{\text{Mean of}\{V_{ab}, V_{bc}, V_{ca}\}} \quad (2-5)$$

It is important to also note the following according to [6]; line to neutral voltages should not be used with equations (2-3) and (2-5) as the zero sequence components can give incorrect results. Though the two methods are seen to give thorough analysis of the presence of unbalance on the power system, the IEC 61000-3-13 [4] method is mathematically rigorous compared to the NEMA method. According to the calculations done in [6], unbalance calculated using the two methods can lead to different results. This then leads to an age old question that who is right, Europe or America. Luckily the difference is not that significant. An example given in [6] indicates the difference to be in the region of 1.26%.

2.1.2 Causes of voltage unbalance

The most common causes of voltage unbalance, according to Koch and Pittorino [7] can be summarised in the following list:

- Large and/or unequal distribution of single-phase loads, phase to phase loads and unbalanced three-phase loads;
- Unbalanced networks designs e.g. SWER;
- Electric arc furnaces(EAF) used in the metals industry;
- Long untransposed or poorly transposed transmission lines;
- Unequal transformer tap settings;
- Open phase on the primary of a three phase transformer; and
- Blown fuse on a three phase capacitor bank.

2.1.2.1 Unequal distribution of single phase loads

According to Koch and Pittorino [7], many loads are single-phase by their nature, and their connection to the grid will give rise to some level of unbalance. This fact is evident to even the non-descending eye, as most of residential loads are single phase supply in South Africa. Koch and Pittorino [7] give examples of some of the large commercial single phase loads summarised as follows; street lighting, single phase induction motors, traction or rail loads and SWER. During the design of such networks it is standard practice to distribute the loads evenly across the three phases, however, this approach does not eliminate unbalance. According to the

author's experience, the design and performance engineers are often required to monitor unbalance on a regular bases and change the point of connections until a balanced system is achieved.

2.1.2.2 Arc furnace

The electric arc furnace (EAF) is a type of furnace which uses electricity as a method of heating for the production of steel. EAF are used primarily for recycling steel. The scrap metal processing method, as explained in [8], uses the electrical arc to melt the scrap and the molten scrap is converted in to steel plates. The process is similar to the occurrence of a short circuit on a normal power system. The heat generated by the plasma of the arc melts the metal to liquid form. According to [8], it is also necessary to have high voltage in order to get a longer arc. .

According [8], an EAF supplied by a step down transformer (MV to LV). The transformers are specially designed to withstand the considerable asymmetrical currents created by the arcing process. The protection settings are also adjusted to high values of fault currents in order to avoid nuisance tripping.

2.1.2.3 Line transposition

The layout of conductors on a line structure has a bearing effect on the symmetry of three phase power supplied to the end customer. This is due to the fact that current carrying conductors laying in close proximity influence each other through electric and magnetic fields. The influence by adjacent fields is dependent on distance i.e. the closer the conductors are the higher the influence. To take an example of a flat formation line structure typically used in distribution networks, the conduct in the middle experiences higher influence by adjacent conductors compared the to those on either side. The presence of high magnetic fields alters the impedance of the middle phase hence resulting in an unbalance in the system. To limit the impact of this effect on the line, transposition is implemented. Transposition simply explained, is the process of alternating the position of the conducts according to the geometry of the line structures. The process limits the exposure of one phase to higher fields as compared to others. According to [9], transpositions are often used in long transmission lines as a means of balancing fundamental frequency impedance. Transposition is easily implemented on long transmission lines, however, it a challenge on distribution line [9].

2.1.2.5 Single phasing

According Koch and Pittorino [7], single phasing can be explained as a state when a three-phase system loses one of the phases. In the event of single phasing, an immediate condition of

unbalance due emerges to the one phase not carrying current. The common occurrence of single phasing in distribution networks is due the blow-up of fuses and faulty line switch gear e.g. air-break switches.

2.1.3 Effects of voltage unbalance on induction motors

2.1.3.1 Motors

Induction motors are adversely affected by the presence of voltage unbalance, according to von Jouanne and Banerjee [1]. This is a well studied phenomenon with publications dating as early as 1950's [1]. Induction motors are very common in industrial environment [1]. The author had the privilege of working in a coal power station where induction motors are used extensively to pump water and drive massive fans hence can attest to the previous statement.

According to [6], current unbalance generated by the presence of voltage unbalance can be multiple folds in magnitude compared to voltage unbalance. The presence of this current can lead to heating and damage of the insulation material of the windings. The unbalance current is generally negative sequence. According to [1], negative sequence currents generate opposing torque in the motor. Simply explained, the motor starts to generate motion in the direction opposite to the desired. This leads to pulsation and noise in a motor. An example given by Jouanne and Banerjee in [1] show that a 5% voltage unbalance can lead to 30% current unbalance. The damage that can be caused by this current is significant.

If the motor is fully loaded some stator phase windings and the rotor will carry more current than is permitted thus causing extra motor losses ($P = I^2R$). According to Koch and Pittorino [7], what exacerbates temperature rise in a motor is the fact that as I^2R losses increases, while the ability of the motor to dissipate heat does not improve. Hence, the increase in motor heating is much greater than the heat generated by motor losses. This will lead to a reduction in motor efficiency while reducing the insulation life. Thermal effect on insulation is a thoroughly studied subject [3] [6][7]. In order to comprehend the net effect of unbalance in induction motor, figure 2-3 shows that the life expectancy of a motors halves with every 10°C of temperature increase.

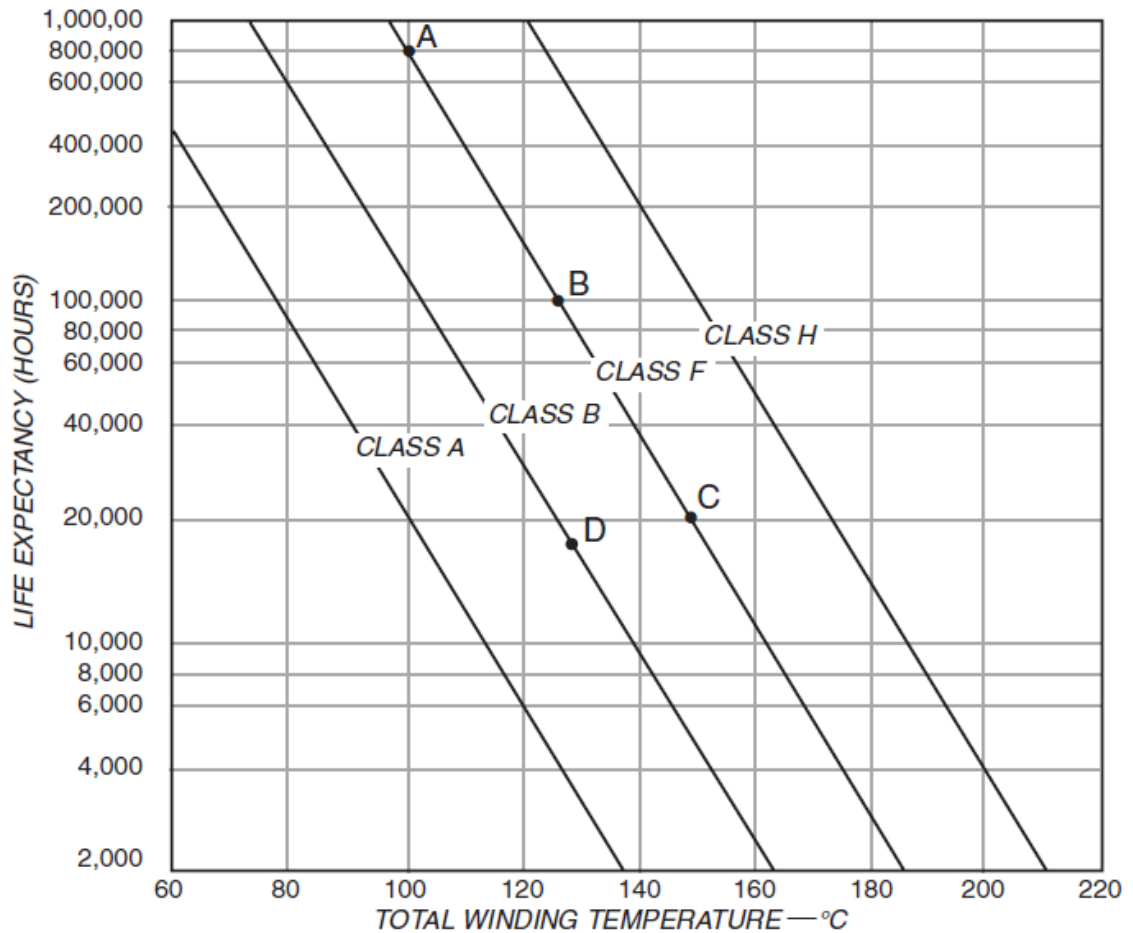


Figure 2-3: Thermal effect on average life of insulation [10]

The adverse effect of unbalance on induction motors has lead NEMA to develop a practical tool engineers can use to derate the motor in the presence of voltage unbalance [2][11]. The derating factor as a function of voltage unbalance is shown in figure 2-4. This curve assumes that the motor is already delivering the rated load. According to this curve it is required that any motor should be built to handle 1% unbalance and thereafter it should be derated depending on the level of unbalance.

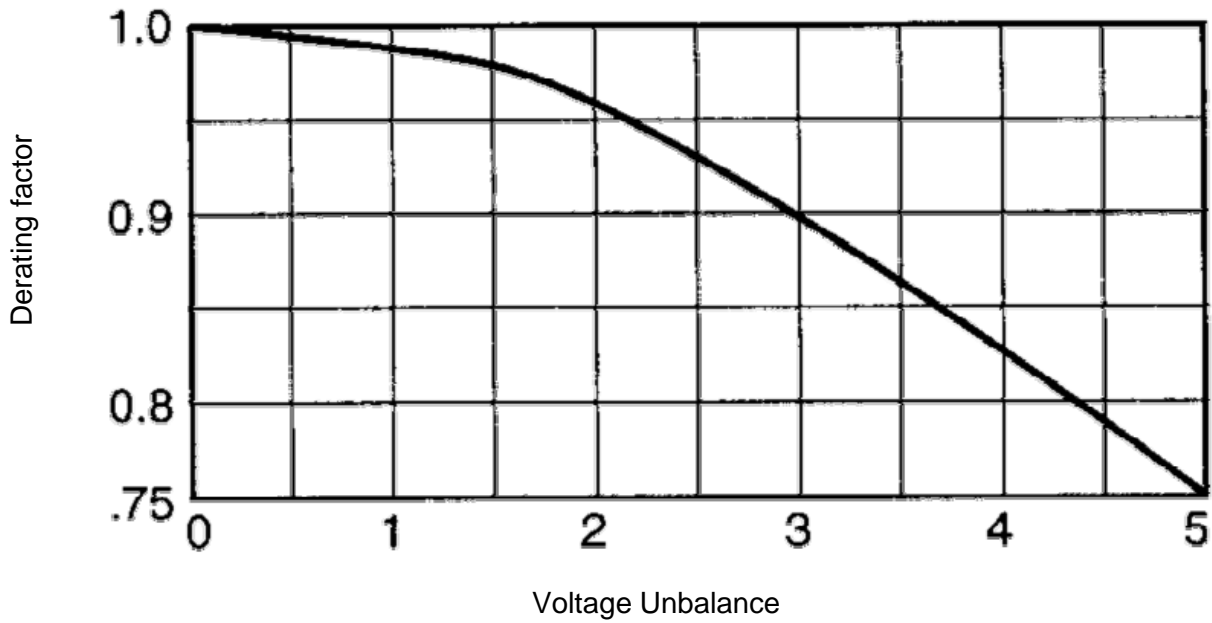


Figure 2-4: Derating curve for motors [11]

According to [6], it has been determined that derating is dependent on motor size.

2.1.3.2 Variable speed drives

According to von Joanne and Banerjee [1], power electronic converters serve as the interface for many large electronic loads. The example of some the most common application is three-phase uninterruptible power supplies (UPSs) and variable speed drives (VSD). A typical VSD can be divided into a two stage process. The first stage is AC to DC converter composed of diodes (e.g. full wave bridge rectifier). The second stage is a pulse width modulator (PWM) converting the now DC supply from the first stage to AC. The PWM circuit is primarily composed of semiconductive devices like IGBTs. A typical circuit diagram of VSP is shown in figure 2-5..

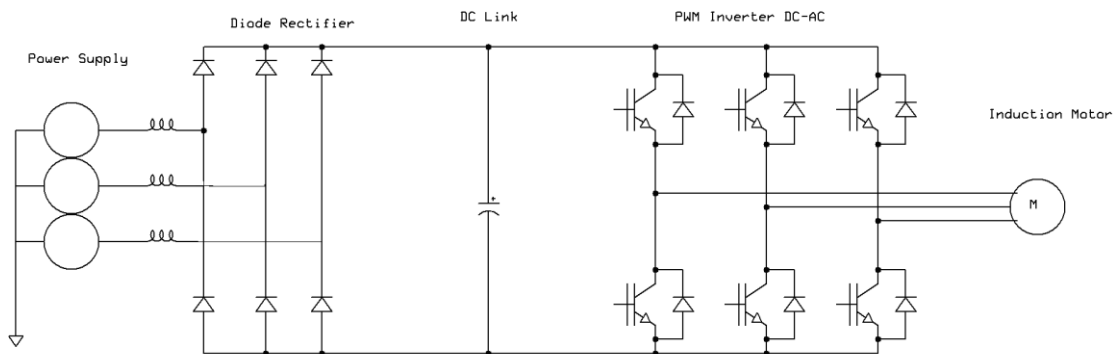


Figure 2-5: Circuit diagram of VSD[1]

According to [1] and [6], rectifier systems draw non-sinusoidal current waveforms from the AC supply. The typical wave shape drawn is what is known as “double pulse per half cycle” shown in figure 2-6. The harmonic order (h) of the double pulse is given by equation (2-6). There is, however, an important condition that must exist in order to generate a authentic double pulse; the AC supply must be balanced.

$$h = 6k \pm 1 \quad (2-6)$$

where h = harmonic order and $k = 1, 2, 3$, giving only the $5^{\text{th}}, 7^{\text{th}}, 11^{\text{th}}, 13^{\text{th}}, \dots$ order harmonics [1][6].

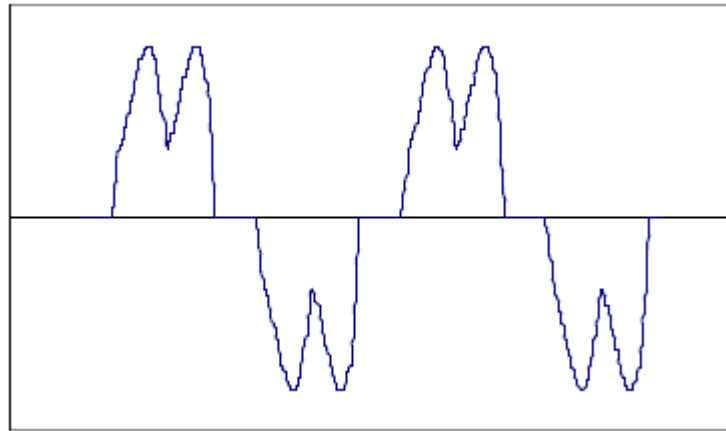


Figure 2-6: Double pulse current waveform

According to [3], as the supply system becomes unbalanced, the resulting current waveform deviates away from the double pulse formation of figure 2-6 to single pulse formation as shown by figures 2-7(a) and 2-7(b) leading to uncharacteristic triplen harmonics. The presence of a 5% voltage unbalance will result in a distorted double pulse current waveform shown in figure 2-7a. Similarly, figure 2-7b shows the effect of a 15% unbalance. The harmonics will lead to high current unbalance draw from the supplier resulting in excessive thermal stresses on the rectifier circuit.

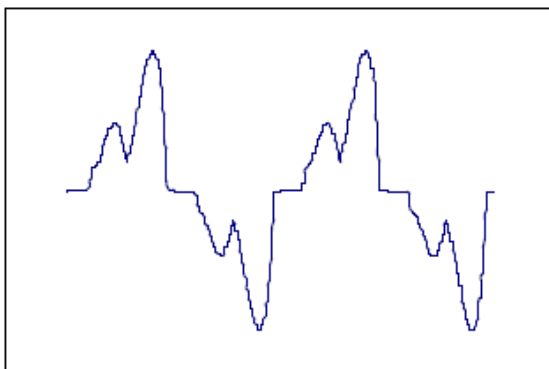


Figure 2-7a Voltage unbalance of 5%

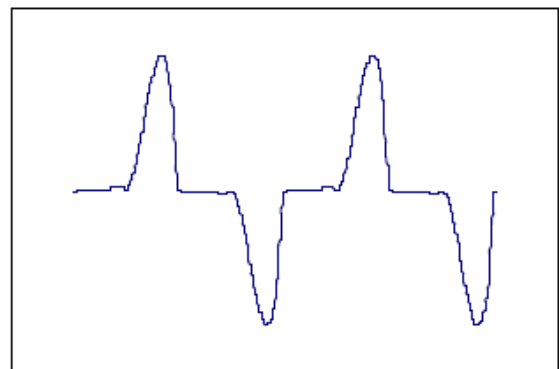


Figure 2-7b Voltage unbalance of 15%

2.1.4 Mitigation

Voltage unbalance is unavoidable, especially on rural systems with long single or dual-phase supply. According to [6] and [7], it is impossible to have a voltage unbalance free supply because of the following reasons:

- random nature of the connection and disconnection of single-phase loads across types of consumers;
- uneven distribution of single-phase loads on the three phase feeders;
- the use of equipment generating uneven current draw on the system;
- the impact of nature on power systems (e.g. radiation generated by the sun); and
- the inherent asymmetry of the power system.

Even though it is impossible to have a perfectly balanced system, it is possible to limit voltage unbalance. Different utilities have their design philosophies aimed at reducing unbalance. The philosophies often employ the well known unbalance mitigation techniques at both utility and equipment levels. The following are some of the techniques used in utilities to limit unbalance according to [6] and [7]:

- redistribution of single-phase loads equally on all phases, though a perfect balance is unachievable due to the random nature of connecting and disconnecting;
- reduction of the system unbalance that arise due to system impedances such as those due to transformers and lines;
- balancing of single-phase regulators;
- line transposition; and
- application of Static Var Compensators (SVC) to balance voltages on the system.

The following are some of the techniques used by end customers to limit unbalance according to [6] and [7]:

- load balancing as applied by utilities, however, at a small scale;
- application of passive networks and static VAR compensators; and

- properly sizing ac side and dc link reactors on an AC variable speed drives.

In addition, as stated by [6] and [7], relays that trip the motor on negative sequence voltage and current can be used to protect induction motors from damage.

2.2 EMC emission allocation

2.2.1 Basic EMC concept

Based on the IEC guidelines for setting emission limits for individual equipment or a customer's installation, the quality of the voltage should be maintained on the power system. The concept of compatibility engineering is used to ensure that installation compare to utility capacity. According to Koch [7][12], Compatibility engineering can be simply explained as the concept of ensuring the requirements of utility networks and customer equipment is mutually compatible i.e.:

- The voltage quality levels provided by the utility do not damage or substantially reduce the expected life span of customer equipment; and
- The currents drawn by the customer does not severely impact the levels of the voltage quality in the utility network.

This concept is demonstrated by figure 2-8. The graph reflects the various levels of emission that a design engineer would have to consider when allocating emissions on a network. The important concept demonstrated by the graph is that the emissions should be kept below compatibility level. The general approach in planning is usually based on 95% probability of exceeding compatibility level. Hence the graph slightly rises above the planning level. Measurements are done at a level below planning level in order to evaluate real impact.

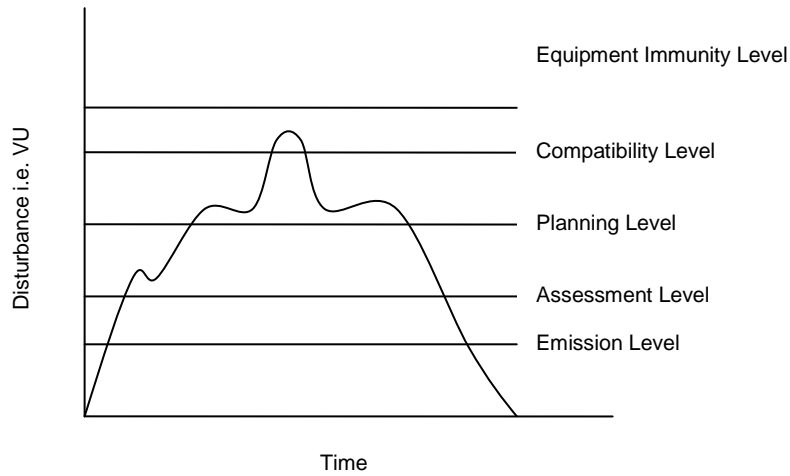


Figure 2-8: EMC planning concept[11]

2.2.1.1 Immunity levels

It is the level of immunity at which customer equipment should archive when tested. It is logical that the immunity level be set higher than all the levels as a precaution to avoid catastrophic equipment failure.

2.2.1.2 Compatibility levels

As defined in IEC guidelines [4][5] and by Koch [7][12], compatibility level is “reference values for coordinating the emission and immunity of equipment or installations which are part of, or supplied by, a supply system in order to ensure the EMC in the whole system is within tolerable levels”. The coordination mentioned in the previous statement refers to balance between EMC emissions and the ability of the equipment to handle the effect thereof e.g. thermal effect to a cable installation. The planning and the compatibility levels are often regarded as one. The power system is dynamic. It can therefore be deduced that it is impossible to coordinate the whole system to achieve zero occurrence of exceeding emission limits. Hence, the stochastic approach of 95% probability of not exceeding limits is assumed in the IEC guideline. The probability is based on levels of entire systems using distribution which represent both time and space variation of disturbances.

2.2.1.3 Planning levels

Planning levels may be considered as emission levels which the utility or customer would like to achieve in order not to exceed compatibility levels for the entire power system. As stated in

2.2.1.2, the planning levels of emission limits may be considered the same as the compatibility level in some cases. The philosophy driving emission limits at this level differs from utility to utility. However, in most cases the drive to achieve specific quality targets may have greater influence. According to [4][5][7][12], planning levels may differ depending on system structure and circumstances. In essence, it could be considered that the planning level is the adaptation of compatibility levels to the characteristics of a particular network. However, it is possible that other utilities may regard these as separate.

2.2.1.4 Assessment level

It is the level at which performance is measured and statistical assessment is used to analyse the results. It is preferred that the level is lower than the planning level in order to assess the full emission on the system.

2.2.1.5 Emission levels

The emission level is defined as follows in IEC guidelines [4] and [5], “the magnitude of the disturbing voltage (or current) vector which the considered installation gives rise to at the point of evaluation”. This level is down to the contribution of individual connections at a point of connection. Logically, the level is much lower since other connections are not taken into consideration. The individual vector U_{di} is shown in figure 2-9.

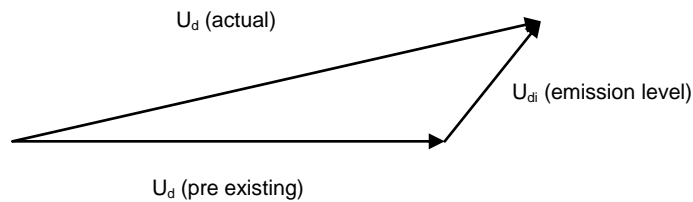


Figure 2-9: Illustration of the emission vector U_{di} [4]

The vector diagram shown in figure 2-9 illustrates the impact of the individual connection without overlooking the impact of other connections and the system ($U_d \text{ (pre-existing)}$). The principle stated in [4] and [5], requires that if a contribution to emission by an individual connection is adding to the total i.e. $|U_{d(actual)}| > |U_{d(pre-existing)}|$, the planning limits set should not be exceeded. It is therefore necessary that allocation of emission levels to individual

connections be derived from the planning levels in order to ascertain that limits are not exceeded. This forms the bases of the approach to allocation defined in IEC 61000-3-13[4].

2.2.2 General principles

The objective is to limit the total disturbance caused by all the disturbing installations to the levels that will not result in voltage disturbance levels that exceed the planning limits. There are three steps to be followed when evaluating allocation emissions given in IEC 61000-3-13[4]. The steps are:

- I. adoption of general summation law for accumulating disturbances arising from various sources;
- II. allocation of global contributions at a given voltage level to ensure coordination between different parts or voltage level system; and
- III. assignment of emission limits to disturbing installations based on the sharing of the global contributions.

Global summation refers to the vector sum of individual emissions. It is the sum of the allowed emission that will not result in planning limits being exceeded. In the process defined in IEC 61000-3-13[4] the global emission is subdivided equally amongst identical individual connections.

2.2.2.1 Summation of numerous sources of disturbance

The summation of individual emission of unbalance is not a simple arithmetic addition. The emission is a vector of both space and time. This leads to complex mathematical analysis. In IEC 61003-13[4], the second law of general summation is endorsed. The formula is given by equation (2-7).

$$D = \sqrt[\alpha]{\sum_i D_i^\alpha} \quad (2-7)$$

where:

- D is the magnitude of the resulting disturbance level after the aggregation of various sources;
- D_i is the magnitude of the disturbance level produced by one of the various sources of disturbance to be combined;

- α is an exponent depending mainly upon the type of disturbance, the chosen value of the probability for the actual value not to exceed the calculated value and the degree to which the individual disturbances vary randomly in magnitude and phase.

The method of general summation is explained in detail in section 2.3.

2.2.2.2 Sharing global contribution between voltage levels

The method proposed in IEC 61000-3-13 [4] allocates the global emission according to voltage level. At the upper end of the voltage spectrum the loads are often three phase and are balanced. However, there are system design generated unbalance emissions which must form part of the global contribution. At MV and below, the presence of unbalance loads is prevalent. The other factor to consider is that there is a level of transfer of emission from one system voltage to the other. Therefore, limits in IEC 61000-3-13[4] are set coordinated according to system voltage level i.e. EHV, HV, MV and LV. The limits are shown in figure 2-10 as L_{uUS} and L_{uMV} . The principles recommended for determining the global disturbance contributions in a illustrated in figure 2-10. The figure illustrates the contributing emissions to the global emission at MV system level is inclusive of disturbance from upstream and downstream networks.

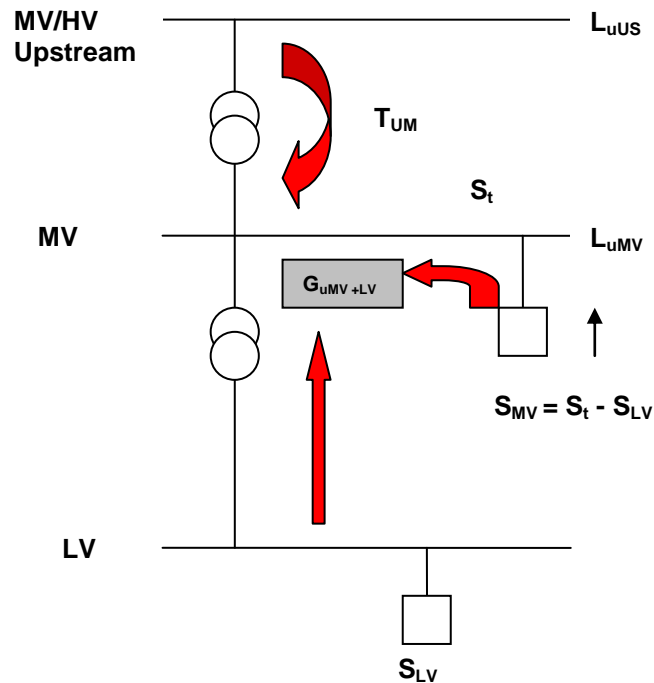


Figure 2-10: Example of a system for sharing global contributions at MV[4]

The idea of limits set according to system voltage makes it easy to calculate emission without knowing all the information about the rest of the power system. If a limit is set for a particular system voltage, the global allocation can be deduced for the set limits. This is illustrated by equation (2-8).

$$G_{MV+LV} = \sqrt[\alpha]{L_{MV}^\alpha - (T_{UM} \cdot L_{uUS})^\alpha} \quad (2-8)$$

where:

- G_{MV+LV} is the acceptable global contribution of the local MV and LV installations (S_{MV} and S_{LV}) to the voltage disturbance in the MV system when the total capacity of the MV system (S_i) is utilised;
- L_{uUS} is the planning level for the upstream system (different planning levels may be needed for the intermediate voltage levels between MV and HV-EHV (this is why the general term of upstream system planning level is used);
- T_{UM} is the transfer coefficient of the disturbance levels from the upstream to the MV system under consideration (determined by simulation and measurements);
- L_{MV} is the planning levels for the considered MV system;
- α is the summation law exponent.

According to IEC, for simplification purposes, the transfer coefficient from the upstream system to a MV system can be taken as equal to 1. In practice however, the transfer coefficient may, because of the presence of three-phase machines on the LV and MV, result in a transfer coefficient of significantly less than 1. It is the responsibility of the system operator or owner to determine the relevant values.

2.2.2.3 Allocation of individual emission limit

The presence of asymmetries generated by the power system form part of the global contribution. It is therefore necessary to consider including a factor which reduces the emissions allocations to individual connections to accommodate the system generated unbalance. A factor K_{uE} is introduced by IEC 61000-3-13 [4] to account for the portion of the allowed global unbalanced level that can be allocated to unbalanced installations. The emission limit for the installation to be connected to a MV system is therefore represented by equation 2-9.

$$E_{ui} = \sqrt[\alpha]{K_{uE}} G_{uMV+LV} \sqrt[\alpha]{\frac{S_i}{S_t}} \quad (2-9)$$

where:

- E_u is the voltage unbalance emission limit of the installation (i) directly supplied at MV (%);
- K_{uE} is the fraction of the global contribution to voltage unbalance that can be allocated for emission from unbalance installations in the considered system (guidelines for the selection of an appropriate value for K_{uE} are given in [4])
- G_{uMV+LV} is the acceptable global contribution to the voltage unbalance in the MV system of the MV system inherent asymmetries and of the unbalanced installations supplied at MV and LV.

A further consideration is that unbalance caused by three-phase customer installations may not necessarily be random in time, but may be assumed, for purpose of allocating emission limits, to be randomly connected to the three phases of the system. Active selection of phase connection is intended to be applied in the case where unbalance is known in order to manage unbalance on such networks.

2.3 General summation law

The study of general summation law applied to EMC emission, in particular harmonics, is an extensively researched topic [13][14][15][16][17]. The method is based on the statistical approach to addition of vectors. When more than one harmonic generator is connected to a power network, the arithmetic addition of the maximum amplitudes will lead to an excessively high value at any given summation point in the system [15]. Two factors make the arithmetic addition excessive:

- The angle of the harmonic (vector); and
- The probability of all connections maximum amplitudes appearing at the same time.

The margin by which the arithmetic sum will differ from the actual maximum harmonic amplitude measured at the common point is what has been most interesting to utilities. For them it meant that there is room to allow more emission on the network without exceeding the limits. The proposed method adding all harmonic sources on the network is represented by equation (2-10)

$$A = k \sqrt[\alpha]{\sum_i A_i^\alpha} \quad (2-10)$$

The equation is based on the assumption that the harmonic angle θ has a uniform probability distribution between 0° and 360° . Several methods have been used to determine k and α including Monte Carlo simulations [15][16]. The various values of k and α for a 95% non-exceeding probability curve are given in table 2-1.

Table 2-1: General summation factors[15]

| Range | Range | N=2 | | N>2 | |
|--------------|-----------|----------|----------------------------|----------|----------------------------|
| 01 | A1 | k | α | k | α |
| 0-360 | 0-1 | 1 | 2 | 1 | 2 |
| | 0.5-1 | 1.3 | 2 | 1.3 | 2 |
| | 1 | 1 | 1 | 1.7 | 2 |
| 0-270 | 0-1 | 0.9 | 1.6 | 0.9 | 1.6 |
| | 0.5-1 | 1 | 1.4 | 1 | 1.4 |
| | 1 | 1 | 1 | 1.3 | 1.4 |
| 0-180 | 0-1 | 0.8 | 1.3 | 0.8 | 1.3 |
| | 0.5-1 | 0.8 | 1.2 | 0.9 | 1.2 |
| | 1 | 1 | 1 | 1.2 | 1.2 |
| 0-90 | 0-1 | 0.9 | 1.2 | 0.9 | 1.2 |
| | 0.5-1 | 0.9 | 1.1 | 0.9 | 1.1 |
| | 1 | 1 | 1 | 1 | 1 |

The contentious issue has always been that there is a probability of exceeding the set limits when using this concept. The concept also holds when there are a large number of sources of emission (N).

2.4 SWER

SWER is defined in [18] as single-phase power distribution system which consists of a single wire supplying a load with the return path through earth. The acronym SWER stands for Single Wire Earth Return. What is unique about SWER is that there is no continuous conductor between the source and the neutrals, hence reducing the number of conductors on the line structure. The neutral current flows via earth electrodes into the mass of the earth. SWER systems, in most cases, are derived from three phase MV feeder lines [18]. SWER was first developed by the New Zealand engineer Lloyd Mandeno in the 1920s [19]. This is the reason it is still widely used in countries like New Zealand and Australia. Lloyd had patent rights registered in Australia [20].

The main purpose of SWER is to power the relatively small loads that are sparsely located. The common application is in rural networks. In densely populated urban areas, the cost of connection is offset by economies of scale. The opposite is true in rural areas where the loads are sparsely located resulting in high cost of connection. SWER is one of the available network design philosophies aimed at reducing the cost of connection. The main advantage of SWER is the fact that it uses a single wire as opposed to the conventional design of three wire system. The obvious cost reduction is in the form of reduced line structures and accessories.

2.4.1 General layout of SWER network

In South Africa SWER networks are build by the state utility Eskom. There are two SWER configurations which have been built in Eskom; SWER derived from a single wire connection to MV feeder and the other derived from dual wire connection to two phases of the MV feeder.

2.4.2 SWER from dual-phase connection

SWER derived from two phases of the MV feeder uses an isolating transformer to electrically isolate the source system from the SWER system, refer to figure 2-11 and 2-12. The isolating transformer prevents the earth fault protection from seeing the load current carrying earths as a permanent earth fault. The isolating transformer connects to two phases of the source line (22 kV 3 phases line) and feeds the single-phase 19 kV SWER line [21].

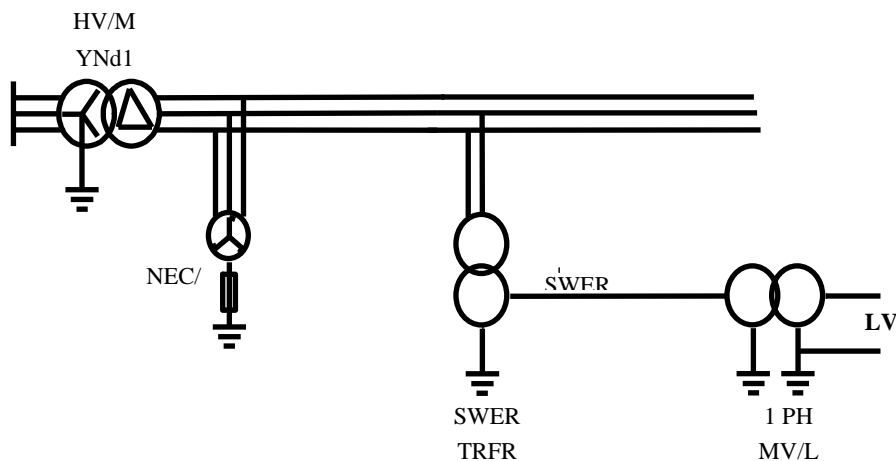


Figure 2-11: A conventional 22kV Eskom distribution system with SWER derived from an isolating transformer [21].

The main advantage of this system is that sensitive earth faults protection setting on the main system is not affected by SWER portion of the network. The isolation transformer provided the shielding for the source three-phase supply. However, the set back of this system is the cost of the isolation transformer.

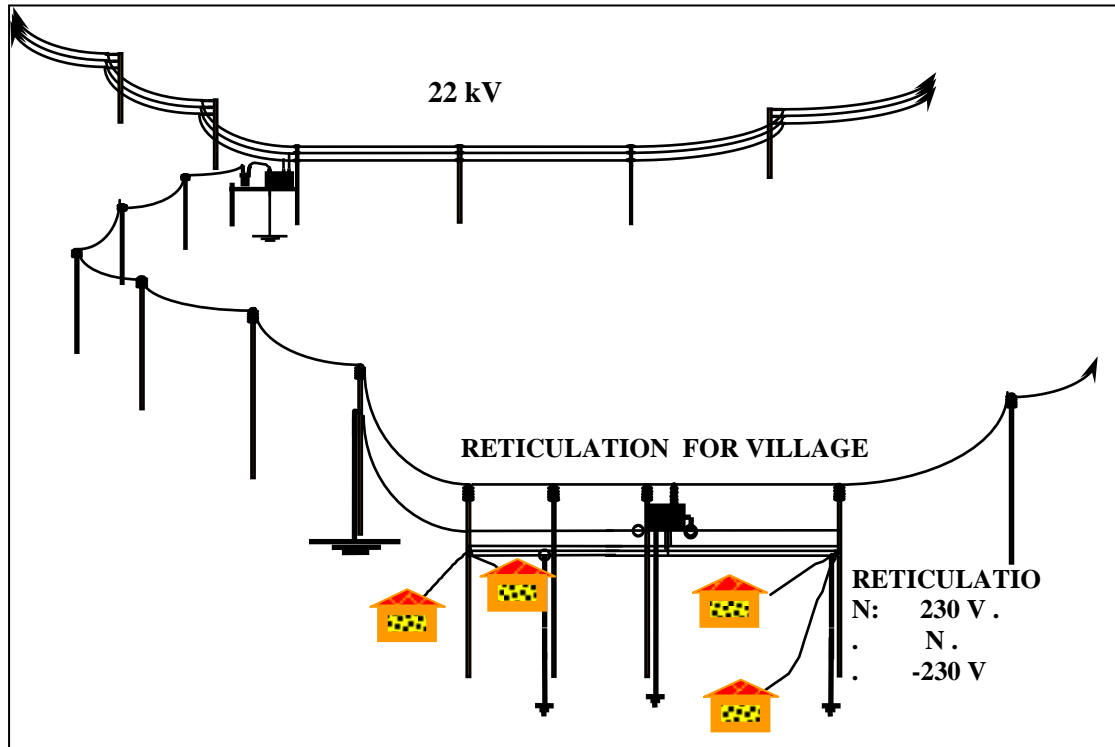


Figure 2-12: SWER network derived from a 22 kV supply [21]

2.4.3 SWER from single-phase connection

The single-phase connection SWER allows for a direct connection to the conventional 33 kV 3 phase (solidly earthed) line, as illustrated by figure 2-13 and 2-14. Direct connection means that there is no isolating transformer and therefore the customer transformers are connected directly to the feeder line (1 phase of the 3 phase 33 kV line).

The earth fault protection settings on the feeder line is either omitted or circumvented by balancing the SWER loads on all three phases and having a higher earth fault setting. The main advantage of this system is the relatively low cost of connecting SWER line to a conventional line. The elimination of a transformer provides the cost reduction. According to Geldehyus [21], the disadvantage is the effect on earth fault protection on the three-phase source. The return path for current will be through the earthing of the source transformer.

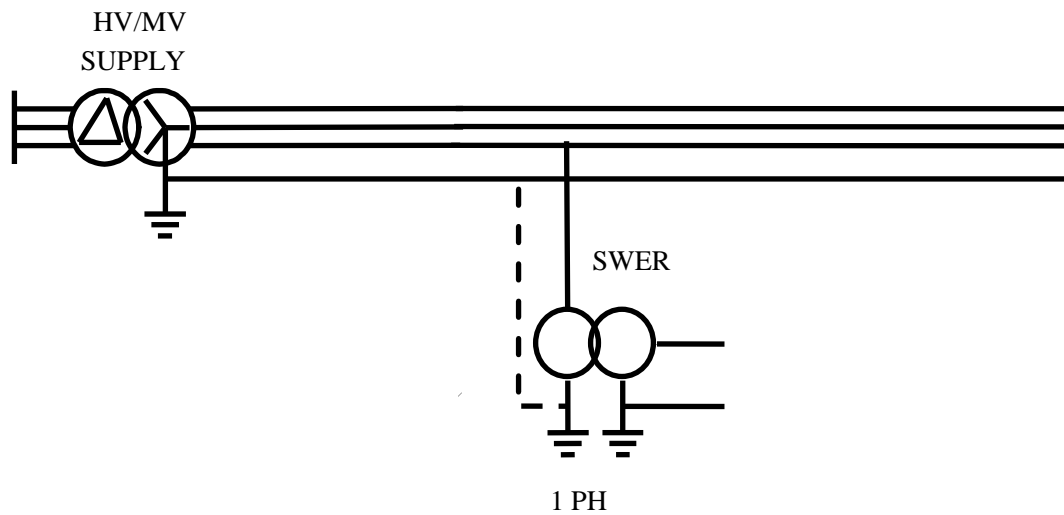


Figure 2-13: SWER network derived from 33 kV supply: circuit [21]

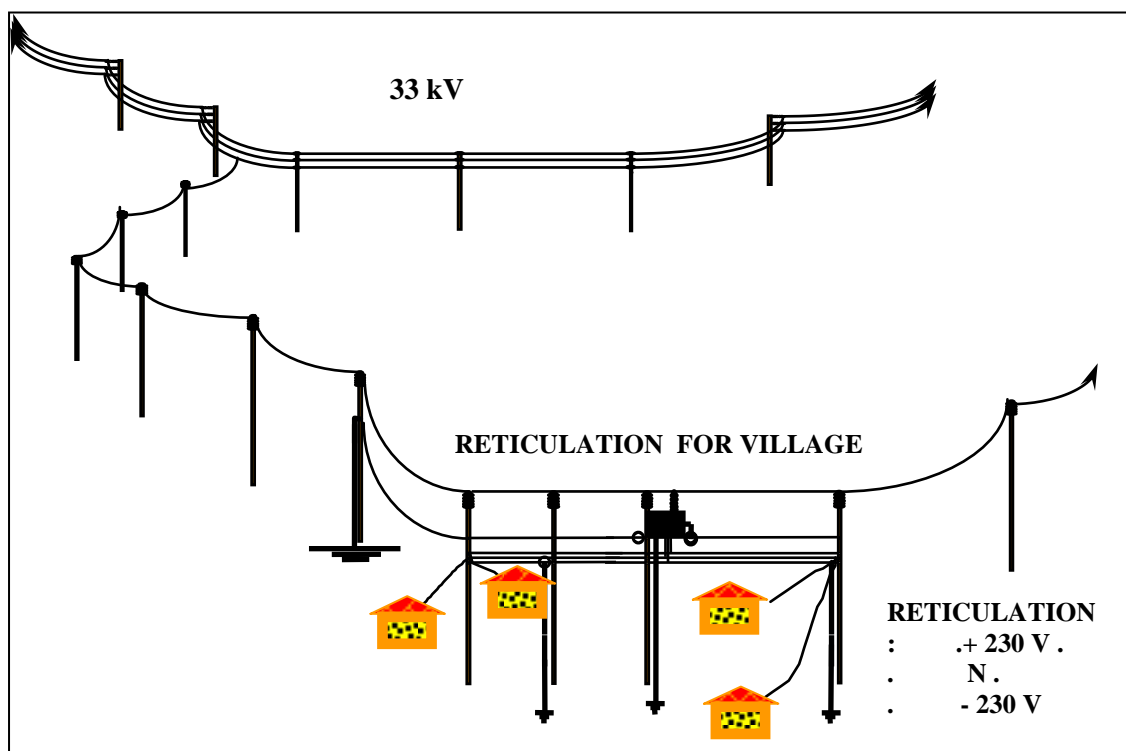


Figure 2-14: SWER network derived from 33 kV supply [21]

2.4.3 System parameters

2.4.3.1 Voltage

The MV system voltage of SWER is 19.1 kV (equivalent to phase voltage of 33 kV line) for Eskom application. The decision for this voltage is based on the following reasons:

- voltage has to be as high as possible to allow for maximum power transfer;
- the gap between load current and fault current should be significant for proper operation of the protection system; and also
- to align SWER to the 33 kV system.

The advantage of this system voltage is that the standard 33 kV equipment can be used.

2.4.3.2 Current

The maximum load current on a SWER system is determined by the ability to distinguish between load and ground fault current. The criterion that was decided on was to ensure that the SWER line would be at least as safe as 11kV lines that are currently in use. Applying this criterion Eskom found that a continuous current of 25A and a fault clearing level of 30A could be applied. In addition to this, the design has to ensure that interference and fault induction is co-ordinated with any telecommunication lines that may be in the area.

2.4.3.3 Power

The 25A and 19.1 kV criteria provide for a maximum feeder power of 475 kVA. Taking load profile into consideration it was adequate to have a maximum of 400 kVA isolation transformer.

2.4.4 Advantages of SWER

As stated in 2.4.3, SWER offers a significant cost savings compared to conventional three phase solutions. The main cost savings are around line structures because of the reduced number of conductors. The following are design changes to the conventional three-phase supply that result in the cost reduction one conductor as opposed to three,

- less pole top equipment i.e. insulators, line hardware, etc.;
- long spans;
- fewer switching and protection devices;
- reduced construction requirements;
- simplicity of design, which allows for speed of construction (stringing);

- reduced maintenance cost because of reduced equipment;
- no conductor clashing, leading to reduced failures;
- environmental impact is less due to reduced clearance requirements and visual obstruction; and
- the use of shorter and lighter poles aids construction in remote areas and different terrain. [18][19][20][21].

2.4.5 Limitations and disadvantages of SWER

Though SWER is generally accepted as a viable design for rural electrification, it is not without limitations. The challenges of operating SWER systems can be divided into two, the first being system design constraints and the second social dynamics. The latter is left to sociologists to discuss. The design constraints of SWER are covered well in [18] and are summarised below:

- The step and touch potential of SWER is limited to 25V. This requirement can be difficult to achieve in areas where the earth resistivity is too high. The cost of reducing earth electrode resistance of the current carrying earths is potentially high. The charging current of long SWER lines is potentially high and will increase the burden on the source line. The ability of the earth electrode to carry the charging current limits the length of the SWER line.
- The SWER system introduces unbalance to the source three phase system. However, it is possible that SWER can improve the balance of the system. SWER has very low fault levels, which makes the protection system unable to sometimes distinguish between peak loads and short-circuit faults.
- Rate of voltage drop as load increases is more than in a conventional three-phase system. The return path is more resistive than in a conventional delta system.
- It is limited to areas where the earth resistivity is within the 1000 Ohms-meter range.
- A concern with loading three phase system with single phase loads is the generation of negative phase sequence currents. Care must therefore be taken to ensure that quality of the three phase supply is not affected by unbalanced single phase loading.
- Interference with telephone lines due to Earth Potential Rise (EPR) makes it mandatory to have large distances between SWER lines and communication lines.

- During off peaks there is a significant rise in capacitive ground current.

CHAPTER 3 ALLOCATING UNBALANCE EMISSION LIMITS ON LONG FEEDERS.

3.1 Introduction

The IEC study committee 77A has produced several guideline reports for the 61000 series over and above IEC 61000-3-13[4] that address issues related to unbalance disturbance. The overall approach to disturbance proposed by the 61000 series is:

“MV customers of equal maximum demand at the same point of common coupling should have equal disturbance allocation”.

The harmonics report IEC 61000-3-6 is similar, to a large degree, to IEC 61000-3-13[4]. The harmonics report went further to cover the question of long feeders, which the unbalance report does not cover. In this chapter the method presented for long feeders for harmonic emissions is studied closely. The method is then tested on unbalance emissions. The compatibility of the method to both harmonics and unbalance is discussed.

3.2 Harmonics allocation IEC61000-3-6

IEC 61000-3-6[5] is a guideline for allocation of harmonic emission limits in MV systems drawing distorting current with harmonics in the range of 2 to 40. It gives guidance to the system operator to determine equitable harmonic levels for each of the individual customers connected to the network. The responsibilities of the parties involved, which in most cases is utility and customer, are outlined. On one hand the utility sets limits to which customers must adhere to, and on the other, the customers control their emission to avoid surpassing the set limits. The limits set by the utility are aimed at keeping the harmonic emissions on the system within the planned levels. The primary principle presented in the guideline follows the IEC 61000 series:

“MV customers of equal maximum demand at the same point of common coupling should have equal harmonic allocation.”

The general principle presented is similar to the one for voltage unbalance in IEC 61000-3-13[4]. The principle is based on a coordination of disturbances where there are multiple sources on one system. The concept of general summation is used to calculate combined disturbance on a system. The summation is non-linear and works with stochastic 95% values rather than

absolute, deterministic limits [4]. This accounts for the time variation between the individual sources of harmonics.

The guideline presents the three stage approach to allocation just like the voltage unbalance guideline. The summary of the stages is given in table 3-1. The stages are intended to provide a trade off between time and the complexity of determining accurate individual allocations. The first stage is based on the ratio between the individual maximum demand and the short circuit rating at the PCC (S_i/S_{sc}) being less than 0.2%. No further calculations are necessary to determine the exact emission because the effect of such a customer will be minimal on the network [5].

Stage 2 is reserved for maximum demand loads which yield a higher ratio of S_i/S_{sc} i.e. greater than 0.2%. Much more complicated methods are applied to calculate the harmonic current the customer is allowed to draw from the PCC. The effect of other loads and system generated disturbance are weighed against the planning limits. The general summation law is used to evaluate the total emission [5].

Table 3-1: Stages of allocation [5]

| | Condition | Method of allocation |
|----------------|--|---|
| Stage 1 | $S_i/S_{sc} < 0.2\%$ | Impact insignificantly small. Covered by equipment immunity. |
| Stage 2 | $0.2\% < S_i/S_{sc} < \text{Planning limit}$ | General Summation law approach. System absorption considered. |
| Stage 3 | $S_i/S_{sc} > \text{Planning limits}$ | A detailed study has to be done. |

The report goes into detail on how stage 2 allocations should be calculated. The method draws out a plan of allocation of disturbance to individual customers, taking into consideration the system's ability to absorb disturbances and the contribution of other factors that may be system inherent e.g. line transposition.

The global emission is better explained as the total allowed emission to keep the system from exceeding the limits set. The global emission is shared amongst individual customers according to the agreed maximum demand. The short fall of this principle is that it assumes that

customers with lesser agreed power contribute fewer emissions. The principle also assumes that the distance between customers is negligible

3.3 Harmonic allocation on long MV lines

Along a long feeder short circuit power may vary considerably. According to [4] and [22], the ratio of the supply end to the end of the feeder can be 10:1. Stage 1 allocation proposed by [22], is based on S_i/S_{sc} . If installations of similar agreed power are allocated equal harmonic voltage, installations at the far ends of the feeders will receive a much lower allocation of harmonic current than those at the supply end. Alternatively, if they are allocated equal harmonic current, installations connected to strong points will be given allocations no greater than that given for weak connection points and the power systems harmonic absorption capacity is underutilised. IEC proposes an allocation based on VA as of method of choice. It is considered to be a compromise of the harmonic current or voltage allocation. Emission based on harmonic VA is expressed by the following equation;

$$E_{lhi} = \frac{A_{hMV} S_i^{(1/\alpha)}}{\sqrt{x_{hi}}} \quad (3-1)$$

where:

- S_i is the agreed power of the installation;
- x_{hi} is the MV network harmonic reactance at the point of evaluation of customer's installation "i";
- A_{hMV} is an allocation constant.

The equation is derived from the power equation $P = I^2 R$. Converted into the notation used in IEC, the power equation can be rewritten as indicated by equation (3-2)

$$Q_{hi} = E_{lhi}^2 x_{hi} \quad (3-2)$$

Where Q_{hi} is power in VA. Based on the philosophy of equal VA allocation for all, then we can assume that Q_{hi} is constant.

Therefore:

$$E_{hi} = \frac{\sqrt{Q_{hi}}}{\sqrt{x_{hi}}} \quad (3-3)$$

Q_{hi} expressed in terms of the maximum demand for an individual load S_i is given as:

$$E_{hi} = \frac{A_{hMV} \sqrt[3]{S_i}}{\sqrt{x_{hi}}} \quad (3.3)$$

The allocation constant, A_{hMV} , is used to ensure that harmonic voltage emission does not exceed the planning level. What perhaps gives this method an edge over the other proposed methods is the inverse relation of emission to the square root of x_{hi} . Because of the relation between impedance and feeder length, the method proposed will give an accurate estimate of emission that will not exceed planning limits.

3.4 Proposed voltage unbalance allocation on long feeders

Similar to harmonics allocation proposed in 3.2, a method that takes into consideration the length of the feeder is necessary in order to archive equitable allocation along long feeders. The method for long feeders for harmonics is derived from the basic principle of $V = IR$. A similar approach is proper to apply to unbalance. It is important to note that the equations derived in this chapter refer to negative sequence unbalance, hence the use of negative sequence impedance used for in calculations. In deriving VA allocation method, the following steps were followed:

$$P = I^2 R \quad (3-4)$$

At this stage it is necessary to use express the normal power equation in variables used by IEC for easy of understanding. Equation 3-5 is an expression of unbalance VA.

$$Q_2 = E_{I2}^2 Z_2 \quad (3-5)$$

Where Q_2 is power in VA, Z_2 is the negative sequence impedance and E_{I2} is the unbalance current . Expressing E_{I2} as the subject of the formula results in equation 3-6.

Therefore:

$$E_{I2} = \frac{\sqrt{Q_2}}{\sqrt{Z_2}} \quad (3-6)$$

Based on the philosophy of equal VA allocation for all connections, it can then be assumed that Q_2 is constant for all the connections on the feeder. In order to fall in line with allocation methods that use the customer's maximum demand on application, it is necessary to express the equation in S_i . The individual unbalance allocation can hence be expressed by equation 3-7.

$$\sqrt{Q_2} = A_{2MV} \sqrt[3]{S_i} \quad (3-7)$$

$$\therefore E_{I2i} = \frac{A_{2MV} \sqrt[3]{S_i}}{\sqrt{Z_{2i}}} \quad (3-8)$$

E_{I2i} is the individual unbalance current allocation, S_i is the maximum demand of the individual load, Z_{2i} is the negative sequence impedance at the load and A_{2MV} is the allocation factor that corrects the allocation in order that the net emission on the feeder does not exceed the set limits. The α brings in the effect of general summation law i.e. the sum of vectors as discussed in chapter 2. The maximum demand and negative sequence impedance are relatively easy to work out, however, the A_{2MV} requires more thought. The allocation factor has to take in to consideration the current and future network demands, the system generated unbalance and the allocations at various system voltages e.g. EHV and HV.

3.5 Calculating the allocation constant A_{2MV}

The uniform loading approach used for harmonics is investigated for application on unbalance. The approach reduces the complexity of the problem by eliminating the dynamics related to load size and point of connection on the feeder. The method requires less information compared to earlier methods used [22].

3.5.1 Calculating current and voltage allocation, considering length of feeder.

The most critical assumption in deriving a workable equation for A_{2MV} is that the load is evenly distributed along the feeder. This is illustrated by figure 3-1. A typical feeder is comprised of random load sizes at various points of connection. The method proposed averages out the loads along the feeder in order to reduce the complexity that variable load sizes and point of connection introduce in calculating global allocation constant.

Consider the position along the feeder is measured by z_2 , the total negative sequence impedance of the line seen looking upstream from the point in question. It is assumed to vary from z_{21} to z_{22} from the sending end to the far end of the feeder (see figure 3-1).

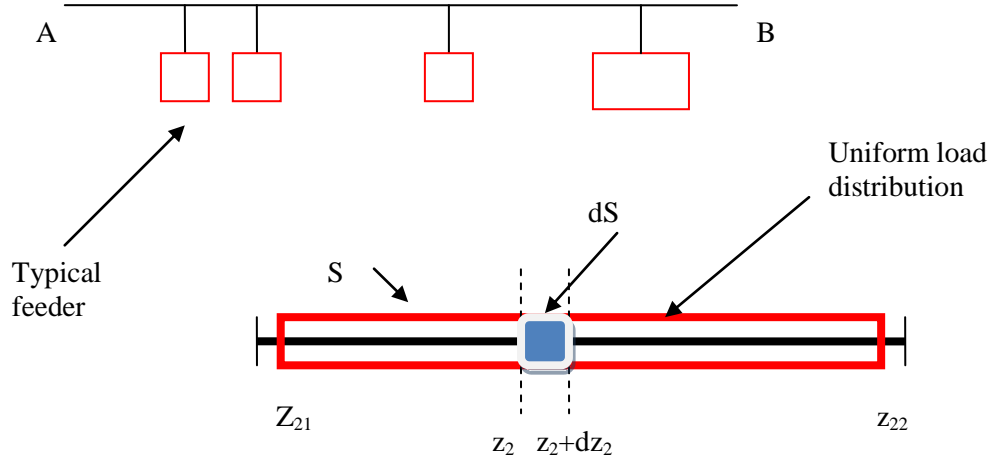


Figure 3-1: Distributed uniform load

Let the load connected between z_2 and $z_2 + dz_2$ be

$$dS = s dz_2 \quad (3-9)$$

Where S is total maximum demand (VA) along the feeders is the rate of change of load along the feeder.

$$s = \frac{S}{z_{22} - z_{21}} \quad (3-10)$$

Using the allocation strategy for long feeders (equation 3-7):

$$E_{I2i} = \frac{A_{2MV} \sqrt[3]{S_i}}{\sqrt{Z_{2i}}}$$

E_{I2i} is allocation to an individual load on a feeder. To determine total unbalance current E_{I2} for the feeder, one has to add all the individual allocation on the feeder. Hence:

$$E_{I2} = E_{I21} + E_{I22} + E_{I23} + \dots + E_{I2n} \quad (3-11)$$

Assuming uniform load across the feeder leaves z_2 as the only factor that change.

The contribution between z_2 and z_2+dz_2 is expressed by the following differential equation:

$$dE_{I2i} = \frac{A_{2MV} \sqrt[dS]{dS}}{\sqrt{z_2}} \quad (3-12)$$

Substituting equation 3-9 results in equation 3-13.

$$dE_{I2i} = \frac{A_{2MV} \sqrt[sdz_2]{sdz_2}}{\sqrt{z_2}} \quad (3-13)$$

Considering E_{I2} is a vector, the general summation law is applied resulting in equation 3-14.

$$d(E_{I2i})^\alpha = \left[\frac{A_{2MV} \sqrt[sdz_2]{sdz_2}}{\sqrt{z_2}} \right]^\alpha \quad (3-14)$$

Simplifying 3-14 results in 3-16.

$$d(E_{I2i})^\alpha = A_{2MV}^\alpha z_2^{\frac{-\alpha}{2}} s dz_2 \quad (3-15)$$

$$\frac{d(E_{I2i})^\alpha}{dz_2} = A_{2MV}^\alpha z_2^{\frac{-\alpha}{2}} s \quad (3-16)$$

The net sum of all the individual allocations is determined by integrating equation 3-16 from the sending to the far end (see equation 3-17).

$$\int_{z_{21}}^{z_{22}} \frac{d(E_{I2i})^\alpha}{dz_2} dz_2 = \int_{z_{21}}^{z_{22}} A_{2MV}^\alpha z_2^{\frac{-\alpha}{2}} s dz_2 \quad (3-17)$$

$$E_{I2}^\alpha = A_{2MV}^\alpha s \left[\frac{z_{22}^{\frac{1-\alpha}{2}} - z_{21}^{\frac{1-\alpha}{2}}}{1 - \frac{\alpha}{2}} \right] \quad (3-18)$$

Since $s = \frac{S}{z_{22} - z_{21}}$ from equation 3-10:

$$\therefore E_{I2}^{\alpha} = A_{2MV}^{\alpha} \frac{S}{z_{22} - z_{21}} \left[\frac{z_{22}^{1-\frac{\alpha}{2}} - z_{21}^{1-\frac{\alpha}{2}}}{1 - \frac{\alpha}{2}} \right] \quad (3-19)$$

Assuming that $z_{22} = Rz_{21}$ where R represents the ratio of the sending end impedance and the far end impedance, the equation can be expressed as follows:

$$\therefore E_{I2}^{\alpha} = A_{MV}^{\alpha} S \left[\frac{(Rz_{21})^{1-\frac{\alpha}{2}} - z_{21}^{1-\frac{\alpha}{2}}}{(Rz_{21} - z_{21}) \left(1 - \frac{\alpha}{2}\right)} \right] \quad (3-20)$$

$$\therefore E_{I2}^{\alpha} = A_{MV}^{\alpha} S \left[\frac{z_{21}^{1-\frac{\alpha}{2}} \left(R^{1-\frac{\alpha}{2}} - 1 \right)}{z_{21} (R-1) \left(1 - \frac{\alpha}{2}\right)} \right] \quad (3-21)$$

Simplifying 3-21 results in equations 3-22 to 3-23.

$$E_{I2}^{\alpha} = A_{MV}^{\alpha} S z_{21}^{\frac{-\alpha}{2}} \left[\frac{R^{1-\frac{\alpha}{2}} - 1}{(R-1) \left(1 - \frac{\alpha}{2}\right)} \right] \quad (3-22)$$

$$\sqrt[\alpha]{E_{I2}^{\alpha}} = \sqrt[\alpha]{A_{MV}^{\alpha} S z_{21}^{\frac{-\alpha}{2}} \left[\frac{R^{1-\frac{\alpha}{2}} - 1}{(R-1) \left(1 - \frac{\alpha}{2}\right)} \right]} \quad (3-23)$$

$$E_{I2} = A_{MV} \sqrt[\alpha]{S} z_{21}^{\frac{-1}{2}} \sqrt[\alpha]{\left[\frac{R^{1-\frac{\alpha}{2}} - 1}{(R-1) \left(1 - \frac{\alpha}{2}\right)} \right]} \quad (3-24)$$

It can be shown using graphs of various values of α that the factor:

$$\sqrt[\alpha]{\frac{R^{1-\frac{\alpha}{2}} - 1}{(R-1)\left(1-\frac{\alpha}{2}\right)}} \approx R^{-0.3} \quad (3-25)$$

A similar approximation was used in [22]. It can be concluded

$$\therefore E_{I2} = \frac{A_{MV} \sqrt[\alpha]{S}}{\sqrt{z_{21}}} R^{-0.3} \quad (3-26)$$

The unbalance limits are often expressed in voltage unbalance factor. It is therefore necessary to convert equation 3-26 to voltage unbalance. Using the fundamental equation $V = IR$, voltage unbalance is expressed as follows:

$$E_{u2i} = E_{I2i} z_{2i} \quad (3-27)$$

Substituting equation 3-7 into 3-27 results in 3-28

$$E_{u2i} = \frac{A_{2MV} \sqrt[\alpha]{S_i}}{\sqrt{z_{2i}}} \times z_{2i} = A_{2MV} S_i^{\frac{1}{\alpha}} \sqrt{z_{2i}} \quad (3-28)$$

Equation 3-29 is derived in similar logic as equations 3-12 to 3-14. The derivative of the individual voltage unbalance is expressed as follows:

$$d(E_{u2i})^\alpha = \left[A_{2MV} (dS)^{\frac{1}{\alpha}} \sqrt{z_{2i}} \right]^\alpha \quad (3-29)$$

$$d(E_{u2i})^\alpha = A_{2MV}^\alpha dS \sqrt{z_{2i}} \quad (3-30)$$

Substituting equation 3-9 into 3-30, 3-31 results.

$$d(E_{u2i})^\alpha = A_{2MV}^\alpha (sdz_{2i}) \sqrt{z_{2i}} \quad (3-31)$$

$$\frac{d(E_{u2i})}{dz_{2i}} = A_{2MV}^\alpha z_{2i}^{\frac{\alpha}{2}} s \quad (3-32)$$

The net sum of all the individual allocations is determined by integrating equation 3-32 from the sending to the far end (see equation 3-33).

$$\int_{z_{21}}^{z_{22}} \frac{d(E_{u2i})^\alpha}{dz_2} dz_2 = \int_{z_{21}}^{z_{22}} A_{MV}^\alpha z_2^{\frac{\alpha}{2}} s dz_2 \quad (3-33)$$

$$E_{u2}^\alpha = A_{2MV}^\alpha s \left[\frac{z_{22}^{1+\frac{\alpha}{2}} - z_{21}^{1+\frac{\alpha}{2}}}{1 + \frac{\alpha}{2}} \right] \quad (3-34)$$

Since $s = \frac{S}{z_{22} - z_{21}}$ substituting in equation 3-34, equations 3-35 to 3-37 results.

$$\therefore E_{u2}^\alpha = A_{2MV}^\alpha \frac{S}{z_{22} - z_{21}} \left[\frac{z_{22}^{1+\frac{\alpha}{2}} - z_{21}^{1+\frac{\alpha}{2}}}{1 + \frac{\alpha}{2}} \right] \quad (3-35)$$

$$\therefore E_{u2}^\alpha = A_{2MV}^\alpha S z_{21}^{\frac{\alpha}{2}} \left[\frac{R^{1+\frac{\alpha}{2}} - 1}{(R-1) \left(1 + \frac{\alpha}{2}\right)} \right] \quad (3-36)$$

$$E_{u2} = A_{2MV} \sqrt[\alpha]{S} z_{21}^{\frac{1}{2}} \sqrt[\alpha]{\left[\frac{R^{1+\frac{\alpha}{2}} - 1}{(R-1) \left(1 + \frac{\alpha}{2}\right)} \right]} \quad (3-37)$$

Similarly, It can be shown using graphs of various values of α that the factor:

$$\sqrt[\alpha]{\left[\frac{R^{1+\frac{\alpha}{2}} - 1}{(R-1) \left(1 + \frac{\alpha}{2}\right)} \right]} \approx R^{0.33} \quad (3-38)$$

A similar approximation was used in [22]. It can be concluded:

$$E_{u2} = A_{2MV} \sqrt[\alpha]{S} z_{21}^{\frac{1}{2}} R^{0.33} \quad (3-39)$$

The objective of these calculations is to determine the allocation factor A_{2MV} . To assure that the calculation for A_{2MV} does consider the effect of other feeders on the network, the load S2 is introduced (refer to figure 3-2)

Determining A_{2MV} :

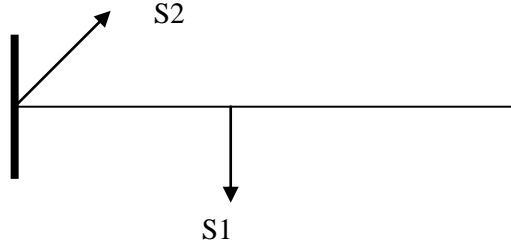


Figure 3-2: Long feeder illustration.

Consider that the voltage unbalance limit for an MV system is the sum of all emission contributors:

$$(L_{uMV})^\alpha = L_{uup}^\alpha + E_{u21}^\alpha + E_{u22}^\alpha \quad (3-40)$$

L_{uup} = Voltage unbalance limit upstream

E_{u21} = Voltage disturbance at far end of a long feeder (S1)

E_{u22} = Voltage disturbance at the sending end (S2)

Since $E_{u21} = A_{2MV} \sqrt[\alpha]{S_1 z_{21}^{\frac{1}{2}} R_1^{0.33}}$ from equation 3-39 and

$$E_{I22} = \frac{A_{2MV} \sqrt[\alpha]{S_2}}{\sqrt{z_{21}}} R_2^{-0.3} \text{ from equation 3-26,}$$

$$\therefore E_{u22} = \frac{A_{2MV} \sqrt[\alpha]{S_2}}{\sqrt{z_{21}}} R_2^{-0.3} \times z_{21} \quad (3-41)$$

Substituting in equation 3-38 results in equation 3-42.

$$(L_{uMV})^\alpha = (L_{uup})^\alpha + \left(A_{2MV} \sqrt[\alpha]{S_1 z_{21}^{\frac{1}{2}} R_1^{0.33}} \right)^\alpha + \left(A_{2MV} \sqrt[\alpha]{S_2 z_{21}^{\frac{1}{2}} R_2^{-0.3}} \right)^\alpha \quad (3-42)$$

From this equation, the allocation constant can be derived as shown by the steps demonstrated by equations 3-43 to 3-45.

$$(A_{2MV})^\alpha = \frac{L_{MV}^\alpha - L_{uup}^\alpha}{S_1 z_{21}^{\frac{\alpha}{2}} R_1^{0.33\alpha} + S_2 z_{21}^{\frac{\alpha}{2}} R_2^{-0.3\alpha}} \quad (3-43)$$

$$A_{2MV} = \sqrt[\alpha]{\frac{L_{MV}^\alpha - L_{uup}^\alpha}{S_1 z_{21}^{\frac{\alpha}{2}} R_1^{0.33\alpha} + S_2 z_{21}^{\frac{\alpha}{2}} R_2^{-0.3\alpha}}} \quad (3-44)$$

$$A_{2MV} = \frac{G_{MV}}{\sqrt[\alpha]{S_1 R_1^{0.33\alpha} + S_2 R_2^{-0.3\alpha}} \times \sqrt{z_{21}}} \quad (3-45)$$

Where G_{MV} is the global emission for MV.

Example

Consider a 132-22kV 15MVA transformer which feeds 3 rural radial feeders. The detail of the feeders is provided in figure 3-3. All the 3 lines consist of three identical conductors in a horizontal configuration formation, transposed, with conductors 400mm apart. Fault level at the transformer is 100MVA. What would the voltage unbalance allocation for a customer 150km down feeder 3 requiring a supply of 400kVA . The impedance for the various conductors for the give configuration of the line is given in table 3-2. Therefore the assumption that, contributions from the other sources has no major influence is acceptable.

Table 3-2: Impedance of conductors

| Conductor | Impedance (Ω/km) |
|-----------|-------------------------------------|
| Fox | 1.00823 |
| Mink | 0.63326 |
| Hare | 0.44122 |

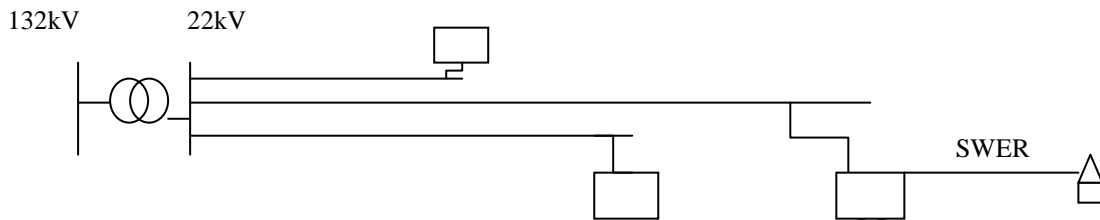


Figure 3-3 : Single line drawing of the network.

Table 3-3: Given and calculated variables.

| Given | | | Calculations | | | |
|---------------|-------------------|------------------|-------------------|---------------|-------------------|----------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | Total length (km) | Total load (MVA) | Weak Feeder (IxL) | Z feeder (pu) | Z of far end (pu) | R = Zfar/Zsend |
| Feeder 1 Fox | 150 | 3 | 450 | 0.31246798 | 0.31913464 | 47.8701963 |
| Feeder 2 Mink | 200 | 2 | 400 | 0.26167769 | 0.26834435 | 40.2516529 |
| Feeder 3 Hare | 300 | 5 | 1500 | 0.27348347 | 0.28015014 | 42.0225207 |

$$V_n = 22 \text{ kV}$$

$$\text{Base } S_b = 1 \text{ MVA}$$

$$\text{Base Impedance} = V^2/S_b = 484 \text{ pu}$$

The limits as prescribed in IEC 61000-3-13 [4] are given in table 3-4

Table 3-4: IEC unbalance limits

| | |
|--------|------|
| EHV/HV | 1.4% |
| MV | 1.8% |
| LV | 2-3% |

Therefore the global emission assuming a general summation constant α of 1.4:

$$G_{MV} = \sqrt[\alpha]{L_{MV}^\alpha - L_{uup}^\alpha} = \sqrt[1.4]{0.018^{1.4} - 0.014^{1.4}} = 0.0076 \text{ pu}.$$

Therefore the A_{M2MV} is calculated using equation (3-45). The impedance at the sending end is base on the fault level.

$$A_{2MV} = \frac{G_{MV}}{\sqrt[\alpha]{S_1 R_1^{0.33\alpha} + S_2 R_2^{-0.3\alpha}} \times \sqrt{Z_{21}}}$$

$$z_{21} = \frac{1}{FL} = \frac{1}{150} = 0.00667 \text{ pu}$$

The calculations for S1, R1, S2 and R2 are provided in table 3-3. S1 and R1 are variables of the weak feeder which according to column 4 of table 3-3 is feeder 3. R2 is the average of the R values for feeders 1 and 2. S2 is the combined load of feeders 1 and 2. Hence:

$$R1 = 42, S1 = 5 \text{ pu}, R2 = 44 \text{ and } S2 = 5 \text{ pu}.$$

Assuming a general summation constant of 1.4:

$$\alpha = 1.4$$

$$A_{MV} = \frac{0.0076}{\sqrt{0.00667 \times \sqrt[1.4]{5 \times 42^{0.3 \times 1.4}} + 5 \times 44^{-0.3 \times 1.4}}} = 0.008322$$

The individual allocation 150km down the line is expressed by equation

$$E_{I2i} = \frac{A_{2MV} \sqrt[1.4]{S_i}}{\sqrt{z_{21}}}$$

$$z_{21} = z_{2source} + z_{2feeder150km}$$

$$z_{2feeder150km} = \frac{150 \times 0.44122}{484} = 0.1367 \text{ pu}$$

$$z_{21} = 0.00667 + 0.1367 = 0.1434$$

$$E_{I2i} = \frac{0.0083 \times \sqrt[1.4]{0.4}}{\sqrt{0.1434}} = 0.0114 \text{ pu}$$

Converting the unbalance current to voltage using the negative sequence impedance of the line:

$$E_{u2i} = E_{I2i} \times Z_2 = 0.0114 \times 0.1434 = 0.0016 \text{ pu}$$

3.6 Discussion of results

The proposed method of allocation of voltage unbalance on long feeders is both logical and easy to implement. The use VA allocation versus current or voltage only methods is proven to achieve the ultimate requirement of equitable share of emissions. The calculation can be completed from information usually available at design phase. This is demonstrated well through the example provided.

CHAPTER 4 RANDOM CONNECTION OF SWER AND THE EFFECT ON VOLTAGE UNBALANCE

4.1 Introduction

Today's electric power systems are perhaps the most complex large-scale technical undertaking development by mankind. The advent of PLCs and microprocessors gave birth to intricate control systems making it possible to interconnect vast amounts of power systems together from nuclear power stations to automatic reclosers switches and arc furnaces. Therefore the network has become a dynamic, ever changing complicated circuit. Deterministic methods of adding system effects have become inefficient leading to over design in most cases [23].

Electric power systems are conceived and constructed to benefit the public for several years in the future. They carry with them a promise of performance and are expected to deliver electric energy with a high reliability. However, future operating conditions can never be stated precisely, and many phenomena governing the design and operating criteria of the power system cannot be predicted with certainty. For example, the power-line transmission structures are designed to withstand mechanical loading caused by adverse weather conditions such as high winds or ice accretion on a conductor, occurrences of which are random [23]. In the absence of certainty the laws of uncertainty applies. To deal with uncertainties faced by system designers and operators, various deterministic safety factors and measurements have been applied [23]. Hence, there are reserve margins in generation capacity, and the n -1 system design philosophy for networks.

The realisation of the deficiencies of the deterministic design and analysis methods, together with the rapidly rising cost and awakened public opposition to many new power developments, has forced the search for new methods of more accurate assessment of the real capabilities of the power system. Prominent among these new methods is probability statistics [23].

The statistical method that deals with probability of state, for example the line is live or dead, which may be caused by a single or various random variables i.e. time, space, etc., is called stochastic process.

Most methods used to solve probabilistic models are analytical, that is, the equations describing the system model were solved either explicitly or numerically [24]. These methods often require one to make assumptions in order to simplify the equations. Some equations are so complex that the best way to solve them would be a simulation.

Numerical simulation is a process of selecting a set of values of a system parameters and obtaining a solution of the system model for a selected set. By repeating the simulation process for different sets of system parameters, a different sample solution is obtained. A numerical simulation procedure applied to problems involving random variables with known (or assumed) probability distributions is called Monte Carlo simulation [24].

4.1.1 Monte Carlo

Monte Carlo is a term used to describe a technique that is based on random numbers and probability, otherwise known as stochastic technique. The technique is used to investigate problems of a random nature. According to [23] and [24], the term “Monte Carlo” was introduced by von Neumann and Ulam during World War II. It is said that Monte Carlo was a code word for the secret work done at Los Alamos. As stated in [23] and [24] it was inspired by gambling casinos at the city of Monte Carlo in Monaco. Monte Carlo method was then applied to problems related to the manufacture of atomic bomb.

Monte Carlo is, today, applied in many fields of studies to solve complex problems [23][24]. Take, for instance, analysing the stock market that is influenced by infinite number of factors. The complexity is made easy by Monte Carlo simulation. The main purpose of Monte Carlo simulation is to solve complex random number problems that are difficult to solve by conventional deterministic methods

As defined in [23] and [24], Monte Carlo simulation applies a method of repeated probabilistic trials, the collection of which can be used to estimate a probability. The outcome from the trials can be analysed further for patterns or trends. Probability statistics is used to derive most probable scenarios. The process does not give definite answers to problems, but help determine high probability outcomes. In summary the Monte Carlo simulation is a step in an analysis, not the answer. The results are used for further analysis in the actual problem being solved. What is important to note about a Monte Carlo simulation is that the more the trials, the better the accuracy of the outcome. The method is easy to implement, but the calculations can be laborious.

4.1.2 Allocation method for New SWER connection in Eskom

Post apartheid, the South African government embarked on a project to redress the disparities created by previous regimes. They initiated a project called The Reconstruction and Development Programme (RDP). The project was aimed at improving infrastructure, with global access to electricity being one of the main objectives. The first obstacle to archiving this goal was the connection cost. The major part of the un-electrified South Africa was in the rural

areas. The residents in these areas could not afford to pay the cost of connection. Therefore, it was left to the government to come up with the required capital. The government had to find ways to reduce the cost of connection to make the project viable. SWER was one of the technologies that were preferred because of its low cost. The custodian of SWER in South Africa is the national utility Eskom [25]. The author, having worked for Eskom for a number of years, was exposed to the technology as applied in Eskom.

Up until recently, SWER connections in Eskom were not strictly monitored because, to a large extent, SWER was an experimental technology. However, the high voltage unbalance measured on some of the backbone networks has led to the need to look closely on how connections should be done, putting more emphasis on phase selection. The common practice that prevailed before could be summarised as follow:

- no clear requirements were followed in terms of size of load that could be connected to a two phase connection;
- phasing was not generally specified on designs which led to construction personnel utilising the easiest two phases for a two phase connection;
- data systems and processes were not designed to be able to capture phasing; and
- simulation tools were not able to model unbalanced networks as no data existed of previous phasing connections [26].

Some of the first method used to control voltage unbalance was the approach to connect 3 large SWER connections at the same point of connection on the backbone [26]. Needless to say that this method would be extremely difficult to implement as most rural connections are sparsely located. Often in some cases new villages emerge due to migration.

It was not until recent that some attention was given to the problem of unbalance in Eskom. The pressure to pay attention to SWER connections and unbalance could be attributed to:

- Emphasis on power quality by NERSA; and
- The growing SWER loads.

The new planning standard covers correction of extreme voltage unbalance due to SWER [26]. The problem of phase selection is emphasised. Detailed studies have been carried out on lines which have been identified as having high voltage unbalance and a fare amount of SWER connections. The study focuses on load readings and phase connections. The configuration of

the network is analysed with the aid of simulation tools and the optimum SWER connections are identified. The fact that loads are stochastic in nature is identified in the standard and therefore this process has to be repeated several times until lasting improvement in voltage unbalance readings is achieved. The process is simplified by the process flow depicted in figure 4-1, extracted from the Eskom planning standard

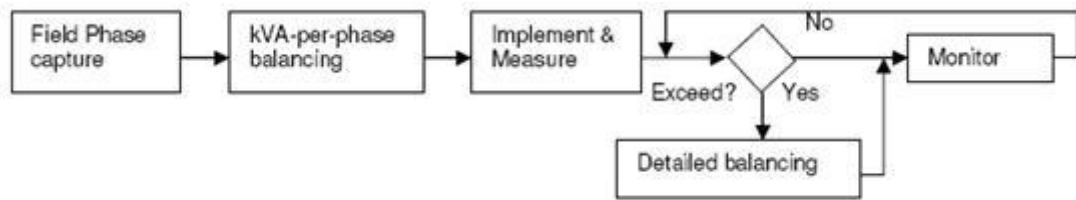


Figure 4-1: Flow chart for SWER connections [26]

The method, as admitted in the standard, will not necessarily result in minimum voltage unbalance. System planners are called upon to use their intuition, after having applied the method, in order to achieve desired levels of voltage unbalance.

This method is also applied when dealing with new connections, the only difference being that the process starts at kVA per-phase balancing stage.

4.2 Monte Carlo simulation procedure

The prime objective of this study is to determine the influence of various variable network parameters on the overall performance of a line with regards to voltage unbalance. When a customer applies for a new connection or in a case where a new network is proposed, power quality factors like voltage unbalance have to be allocated. System planners are faced with a challenge that not all networks are the same. The maximum demand load requested by one client is not the same as the next, and the location of one client differs from the other. These challenges make it impossible for anyone to plan an ideal system with the maximum demands and location of loads equal. The nature of these variable parameters can be considered random.

The Monte Carlo process can be summarised into steps depicted by the flow chart in figure 4-2.

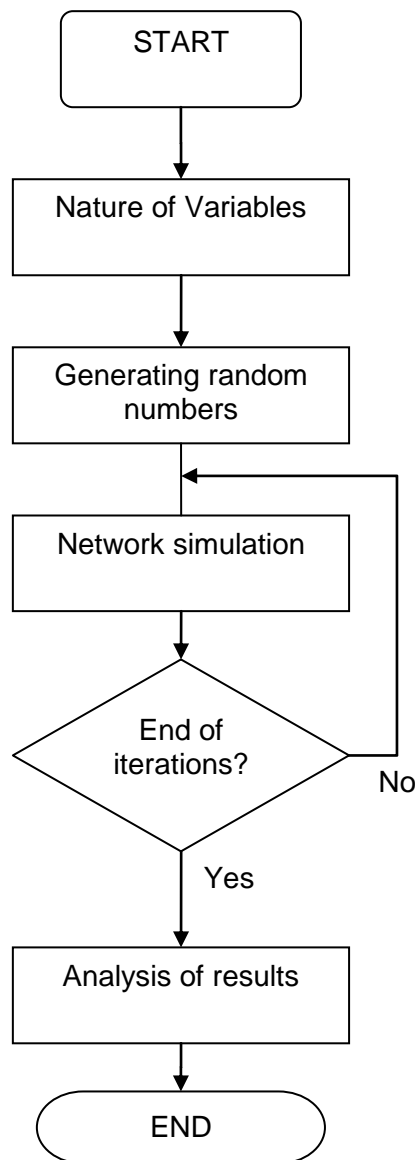


Figure 4-2: Flow chart of the Monte Carlo procedure

4.2.1 Variables

Input variables in Monte Carlo are random as mentioned in the introduction to the chapter. It is therefore important that the statistical distribution be determined in order to proceed to the next step of generating random input numbers to the model. It is often necessary to have historic data of the variables to determine the distribution. In the case where such data is not available, one can make reasonable assumptions based on the information at hand. There are standard procedures to identify statistical distribution as indicated by Raychaudrudi [29].

4.2.2 Random variable generation

When the process of determining variables and their distribution function is complete, random values are generated using the parameters of the distribution function. A random number generator is used. The values generated in this step are used as input to a deterministic model to generate results. This process is repeated several times to produce an array of output values to be analysed in the last step.

4.2.3 Output analysis

Analysis of output values yields data useful for deciding on the impact that various scenarios posed by the original problem. Often probability distributions are generated to assess the impact of input variables or decisions.

4.3 Monte Carlo Input Variables

4.3.1 Introduction

As indicated in the introduction of this chapter, the single phase network system that is considered for this study is SWER. This technology is fully explained in the literature review. The characteristics unique to SWER which would best demonstrate the effect we wish to study in this chapter can be summarised as follows:

- SWER feeders are often long;
- The maximum demand of the each load centres differ vastly;
- The short circuit (MVA) varies by a large margin from the supply end to the loads because of the long length of the line;
- SWER is often fed from a long radial feeder; and
- The villages electrified by SWER are often randomly scattered.

These are some of the factors that a system planner should consider in order to guarantee that emission limits like voltage unbalance are not exceeded. As discussed, most of these factors can be considered random. This study investigates the probability of using a different approach to allocating new connection and the effect on unbalance. To resume this study, it is necessary that one understands the nature of variables and to establish if there is correlation.

4.3.2 Variables

Only variables that have an impact on voltage unbalance were considered for the study. A summary of the variables is given in table 4-1.

Correlation is the measure of how strong the linear relationships between variables is. At the planning phase none of the variables are related. The location of the load centres is erratic, particularly in rural areas. The load sizes differ according to the size of the villages or farms. A phase selection is the responsibility of the planning engineer. Though in normal practice, the phase selection it is the function of load. For purposes of this study, the phase selection will be considered random and independent of load.

Table 4-1: Planning variables

| Variables | Random | Discrete or Continuous | Correlative |
|------------------|---------------|-----------------------------------|--------------------|
| Load | Yes | Discrete | No |
| POC | Yes | Discrete | No |
| Phase selection | Yes | Discrete | No |

4.3.2 Generating random variables

The generation of random numbers can be done on any computer program that has a built in pseudo-random number generator [28] e.g. Pspice, TK-Solver, MATLAB, Excel etc. Excel is the most easily available program of the rest and hence was used in this study [27][28][30]. Excel has additional function to generate random numbers for a specific probability density function and discrete numbers.

The table 4-2 shows the formulae used in excel to archive the desired random numbers.

Table 4-2: Random number generation

| Variable | Function | Excel function | Description | Parameters |
|----------|----------|----------------|--|---|
| Load | Uniform | RAND() | Returns normal distribution numbers. | Max: 400kVA Min: 50kVA |
| POC | Uniform | RAND() | Returns uniform numbers between the given parameters. | Max: 5000m Min: 1000m |
| Phase | Uniform | RANDBETWEEN() | Returns integer between the variables entered. The integers between have equal probability | Between 1 and 3. 1 is AB 2 is BC 3 is CA |

4.4 Network simulations

4.4.1 Simulation tool

There were two simulation tools that were considered for network load flow simulation and they are ReticMasterTM and DIgSILENT *PowerFactory*. Both softwares are proficient in producing voltage unbalance results. DIgSILENT is the superior of the two when it comes to performance and functionality. It can be programmed to run scripts and hence would be easier to use for repetitive modelling required for Monte Carlo. Though the author believes that this was the better program to use, the licence for this program is the more expensive of the two. Because of limited funds, the idea of using DIgSILENT was abandoned for ReticMasterTM.

Reticmaster is a locally developed network simulation program. The program was developed initially for Eskom in 1997. It is specifically designed to model MV and LV reticulation system. Because the program was developed primarily for Eskom, standard network design topologies like SWER are part of the library. This enables the user to simply select from drop down list the network type one would like to connect.

Monte Carlo requires a simulation of multiple trials in order to get a representative output. The simulations are tedious and would require an automated process. ReticMasterTM has a built in

Object Linking and Embedding (OLE) function which enables other Microsoft based programmes to use a function in ReticMaster™. Using programming languages like C++, Visual Basic one can automate ReticMaster™ to perform functions like entering network data, simulation and getting results from a simulation.

*Note: OLE allows an editor to "farm out" part of a document to another editor and then re-import it. For example, a desktop publishing system might send some text to a word processor or a picture to a bitmap editor using OLE.

4.4.2 Simulation

4.4.2.1 Network design

ReticMaster™ has an interactive network design view feature enabling the user to draw a network by selecting pre-designed network objects. The user is able to also design new objects by loading parameters suitable for their application.

Two network designs were used for this study. The first network was composed of six SWER loads fed from a radial three-phase feeder. The second network was similar to the first; however, had fifteen load connections. The two designs were chosen to demonstrate the effect of a number of loads on the outcome. Figures 4-3 and 4-4 shows the networks as drawn in ReticMaster™.

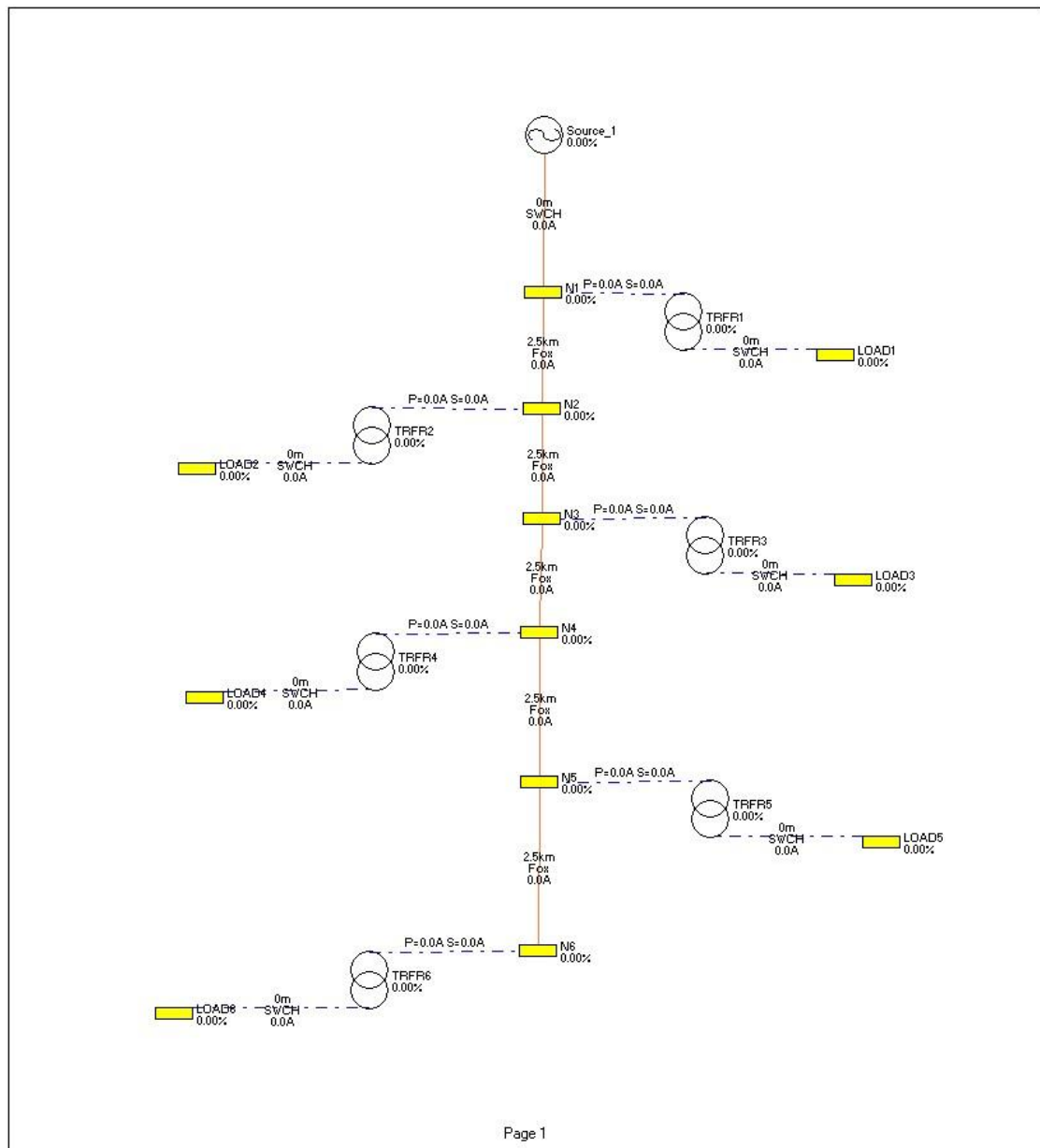


Figure 4-3: Network design with six loads

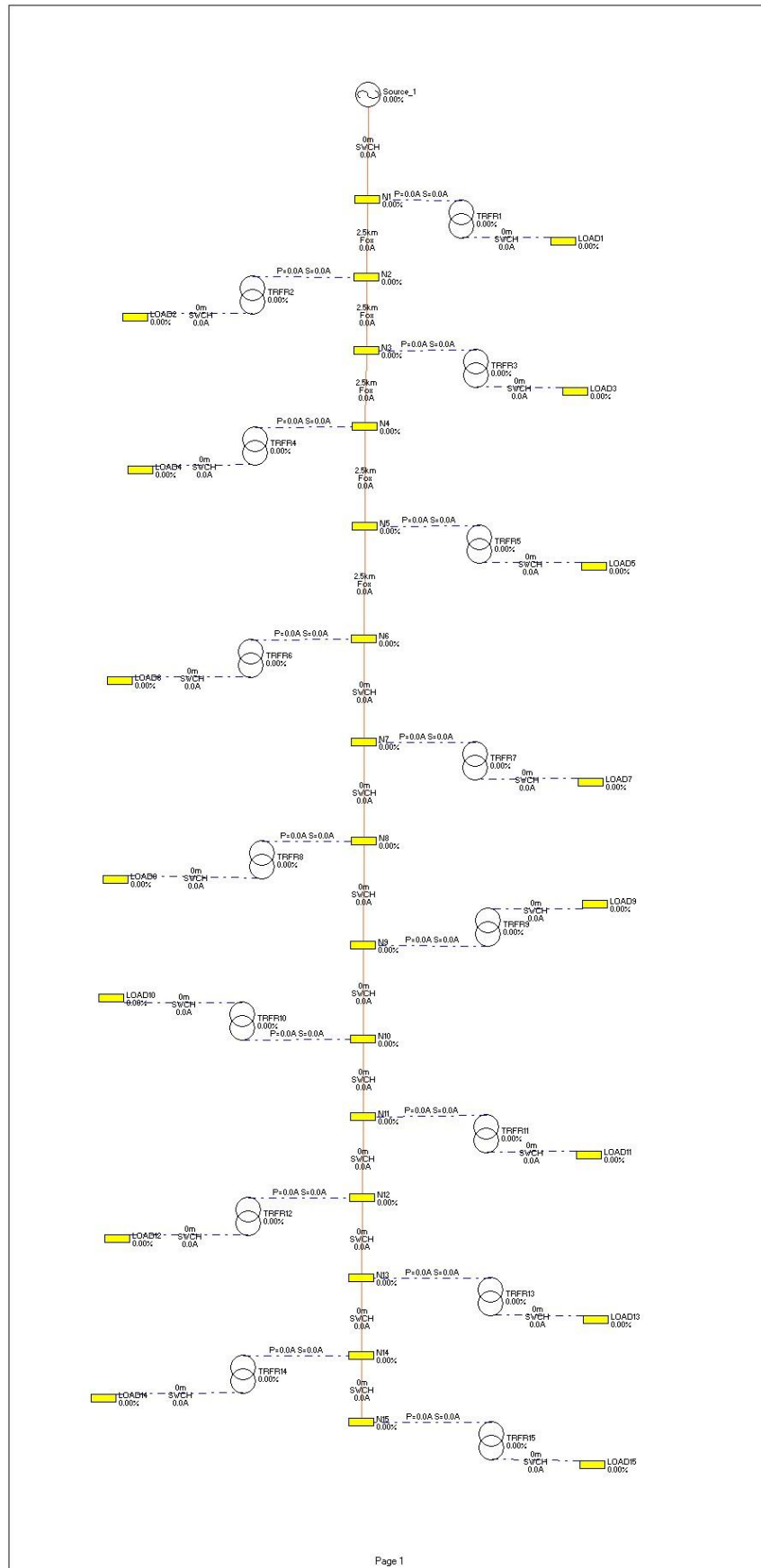


Figure 4-4: Network design with fifteen loads

4.4.2.2 Simulation stages

The overall study was composed of several simulations. The simulation was staged for the purpose to study the impact of each random variable. In the first stage only one of the three random variables was made random, while the other variables were kept constant at average values. For the second stage two variables were made random while one was kept constant. Various combinations of the three variables were considered. The third stage was a simulation with all variables random. Though in principle there is only one variable of the three that a planning engineer can influence i.e. phase selection, the author thought it necessary to study the trends of each variable and their impact on the results. Table 4-3 shows the various stages. The stages set out were implemented for both the six load and the fifteen load network designs.

Table 4-3: Stages of the simulation

| | Random | Constant | Purpose |
|---------|-------------------|--------------|--|
| Stage 1 | Load | POC & Phase | Study impact of each random variable |
| | POC | Load & Phase | |
| | Phase | POC & Load | |
| Stage 2 | Load & POC | Phase | Study impact of combinations random variable |
| | Load & Phase | POC | |
| | POC & Phase | Load | |
| Stage 3 | Load, POC & Phase | None | Study impact of all random variable |

4.4.2.2 Visual Basic programming

The nature of Monte Carlo studies is that they are long and tedious because of the repetition of the calculations. One is often required to calculate thousands of iterations in order to get clear results. It is therefore beneficial to try to automate the process. A Visual Basic program was written in Excel for the purpose of automating the study. Excel has all the basic functions to link the two stages of Monte Carlo which are random number generation and network simulations.

ReticMaster™ is an OLE Automation Server, exposing some of the ReticMaster™ functionality to programs acting as OLE Automation Controllers. ReticMaster™ has a set of OLE commands which can be used by other programs to manipulate data and perform calculations.

Note: The ReticMaster™ OLE commands are available in the user guide.

A macro was written using Visual Basic in Excel to automate the Monte Carlo process. The program was built on the basic Monte Carlo procedure discussed in section 4.2. The random iterations were generated using the pseudo random function `rand()` in Excel. The values generated were uploaded into a network in ReticMaster™ through the OLE commands. Once the settings have been loaded on to the network then, calculation was performed and results generated. The results in ReticMaster™ were then extracted back to excel and saved. The process was repeated 2000 times representing the 2000 Monte Carlo iterations. The full Visual Basic program code is included in appendix B. The overall steps of the program are described by figure 4-6.

Note: The author edited an existing code provided by ReticMaster™ to adopt the code for Monte Carlo simulation. The adaptation of the VB code to suite this study was not a mere retrofit, but the author had to study and understand the code before adding extra functions.

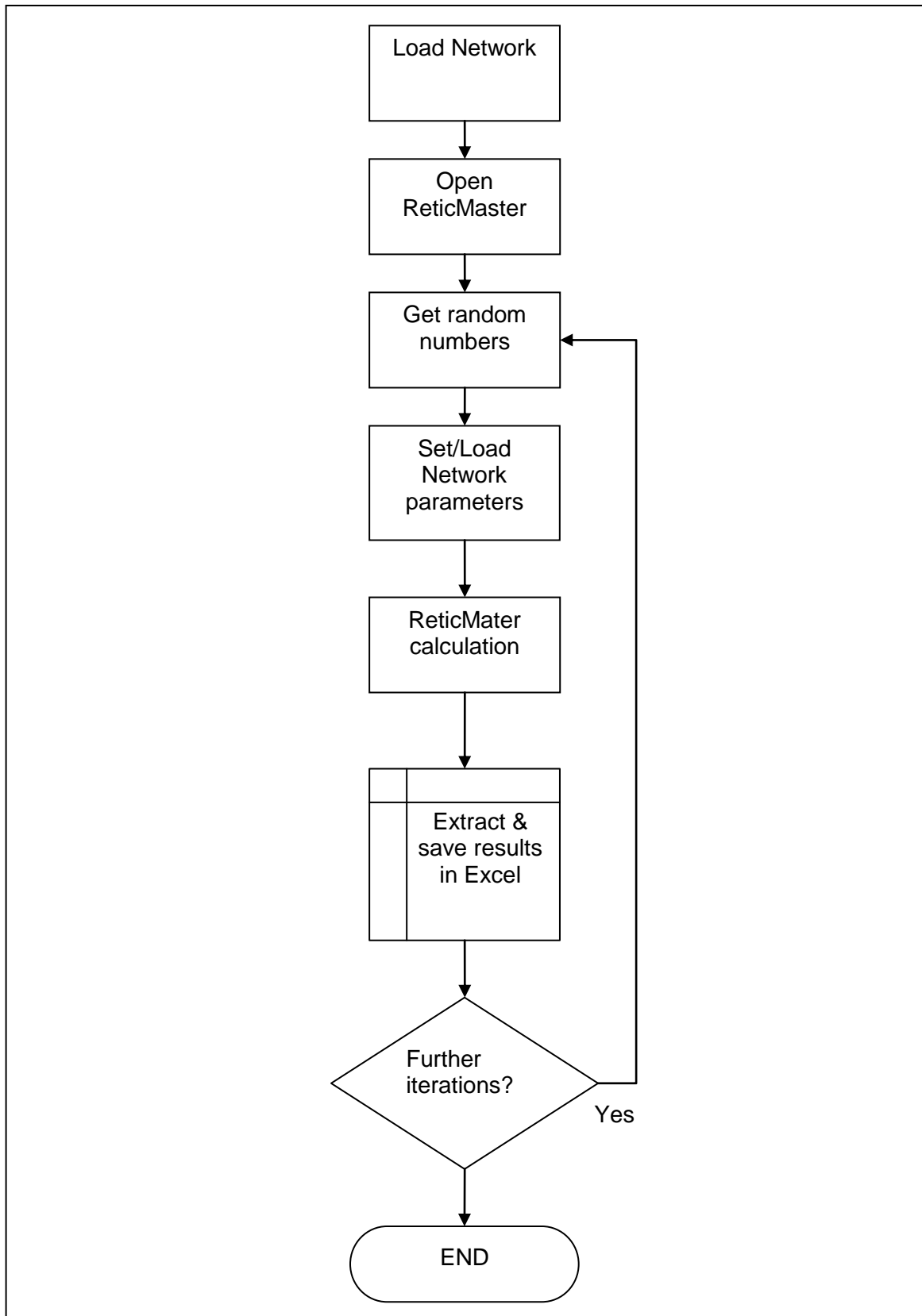


Figure 4-5: Visual Basic program flowchart

4.4.3 Discussion of results

Results generated by ReticMasterTM are a summary of electrical parameters at a given node. The parameters can be selected to show relevant information to the user. For this study, voltage unbalance was the parameter being measured and the rest were used to check if the program was uploading correct information and that each iteration was unique. Since the program shows results of all the nodes of the system, it was therefore necessary to filter the information. Only the nodes with the highest voltage unbalance were considered for this study. This limits the study to worst case scenario of unbalance for each of the iterations. As previously stated that 2000 (N) iterations were done for each scenario, therefore each scenario generated " N " worst cases of unbalance.

In order to give further meaning to the results, a histogram composed of the " N " worst cases was derived for each the scenarios. The summary of the parameters of the resulting histograms are given in table 4-4 and the graph in appendix C. For one to draw a meaningful histogram, it is necessary to select a proper "bin". A "bin" too large will make it difficult to determine the amplitude of the graph. The graph tends to be flat. Too few bins make it difficult to estimate the underlying pmf or pdf in the horizontal direction. Therefore the bin with steps 0.1% was chosen (i.e. 0.1%, 0.2%,...12%). This was in line with the expected unbalance data.

Along with the histogram, the cumulative distribution function (cdf) and the probability mass function (pmf) were generated from the data. These functions were used to determine probability curves for the different scenarios.

Table 4-4: Summary of results

| Simulation | Random | Probability <2% | Probability 2% < P < 3% | Probability >3% | Mean | STD Deviation | Error | Skewness | Kurtosis | Variability | min | max | No. of trial |
|-------------------|----------------|---------------------------|--------------------------------------|---------------------------|-------------|----------------------|--------------|-----------------|-----------------|--------------------|------------|------------|---------------------|
| 6 Load Network | Load | 100% | 0% | 0% | 0.46 | 0.18 | 0.40% | 0.30 | -0.52 | 0.15 | 1.020 | 0.082 | 2000 |
| 6 Load Network | POC | 100% | 0% | 0% | 0.28 | 0.07 | 0.15% | 0.09 | -0.48 | 0.06 | 0.460 | 0.098 | 2000 |
| 6 Load Network | Phase | 98.25% | 1.75% | 0% | 0.99 | 0.43 | 0.96% | 0.26 | -0.23 | 0.35 | 2.225 | 0.203 | 2000 |
| 6 Load Network | Load POC | 100% | 0% | 0% | 0.55 | 0.24 | 0.54% | 0.62 | 0.16 | 0.19 | 1.496 | 0.094 | 2000 |
| 6 Load Network | Load Phase | 65.47% | 27.68% | 6.85% | 1.73 | 0.81 | 1.82% | 0.60 | 0.45 | 0.65 | 5.159 | 0.114 | 2000 |
| 6 Load Network | POC Phase | 77.41% | 19.34% | 3.25% | 1.49 | 0.72 | 1.61% | 0.68 | 0.41 | 0.58 | 4.674 | 0.185 | 2000 |
| 6 Load Network | Load POC Phase | 88.76% | 10.39% | 0.85% | 1.23 | 0.60 | 1.35% | 0.71 | 0.59 | 0.48 | 3.941 | 0.103 | 2000 |

| Simulation | Random | Probability <2% | Probability 2% < P < 3% | Probability >3% | Mean | STD Deviation | Error | Skewness | Kurtosis | Variability | min | max | No. of trial |
|-------------------|-------------------|---------------------------|--|---------------------------|-------------|----------------------|--------------|-----------------|-----------------|--------------------|------------|------------|---------------------|
| 15 Load Network | Load | 29.99% | 38.62% | 31.39% | 2.49 | 0.86 | 2% | 0.14 | -0.25 | 0.69 | 5.287 | 0.330 | 1424 |
| 15 Load Network | POC | 0.00% | 40.00% | 60% | 3.15 | 0.26 | 1% | -0.11 | -0.14 | 0.21 | 3.961 | 2.285 | 1424 |
| 15 Load Network | Phase | 18.33% | 21.28% | 60.39% | 3.68 | 1.81 | 5% | 0.61 | 0.19 | 1.46 | 12.306 | 0.470 | 1424 |
| 15 Load Network | Load POC | 20.58% | 37.43% | 41.99% | 2.87 | 1.01 | 3% | 0.29 | -0.26 | 0.81 | 6.349 | 0.474 | 1424 |
| 15 Load Network | Load Phase | 25.14% | 26.05% | 48.81% | 3.18 | 1.53 | 4% | 0.60 | -0.01 | 1.24 | 9.172 | 0.332 | 1424 |
| 15 Load Network | POC Phase | 12.08% | 17.84% | 70.08% | 4.31 | 2.05 | 5% | 0.68 | 0.46 | 1.65 | 13.567 | 0.443 | 1424 |
| 15 Load Network | Load POC Phase | 20.73% | 22.64% | 56.63% | 3.59 | 1.79 | 5% | 0.73 | 0.45 | 1.45 | 11.568 | 0.276 | 1424 |

All the histogram results show a normal distribution curve with an error less than 5%. In analysing the outcome of this study, it is important to understand the Central Limit Theorem (CLT), said to be one of the most important concepts in probability. It is defined in [32] as follows: “ it states that a sum of random numbers becomes normally distributed as more and more of the random numbers are added together. The Central Limit Theorem does not require the individual random numbers to be from any particular distribution, or even that the random numbers to be from the same distribution. The Central Limit Theorem provides the reason why normally distributed signals are seen so widely in nature”. Whenever many different random forces are interacting, the resulting probability distribution function becomes a Gaussian distribution (or normal distribution) [32].

The study was conducted in a way that made it possible to assess the impact of each random variable, and combinations thereof, on the overall voltage unbalance. As clearly demonstrated in figure 4-6, a high number of single phase loads on a feeder will result in unbalance problems, regardless of systematic allocation of loads. The reason being, other factors that are random by nature and cannot be controlled by design will bring about the unbalance. When there is a reasonable number of single phase loads i.e. 6-to-9, it is possible to connect the loads with less regard for systematic load allocation. The probability that unbalance will be less than the set VU limits of between 1.8 to 2.0% are high i.e. 75%. The factor with more influence on unbalance is phase selection. If the average load is not too high, as is the case in SWER applications, random load allocation has the least impact on VU. If the distances between loads are long, POC has a significant impact on VU. Since the nature of rural loads are sparsely located, it is therefore important to try average POC.

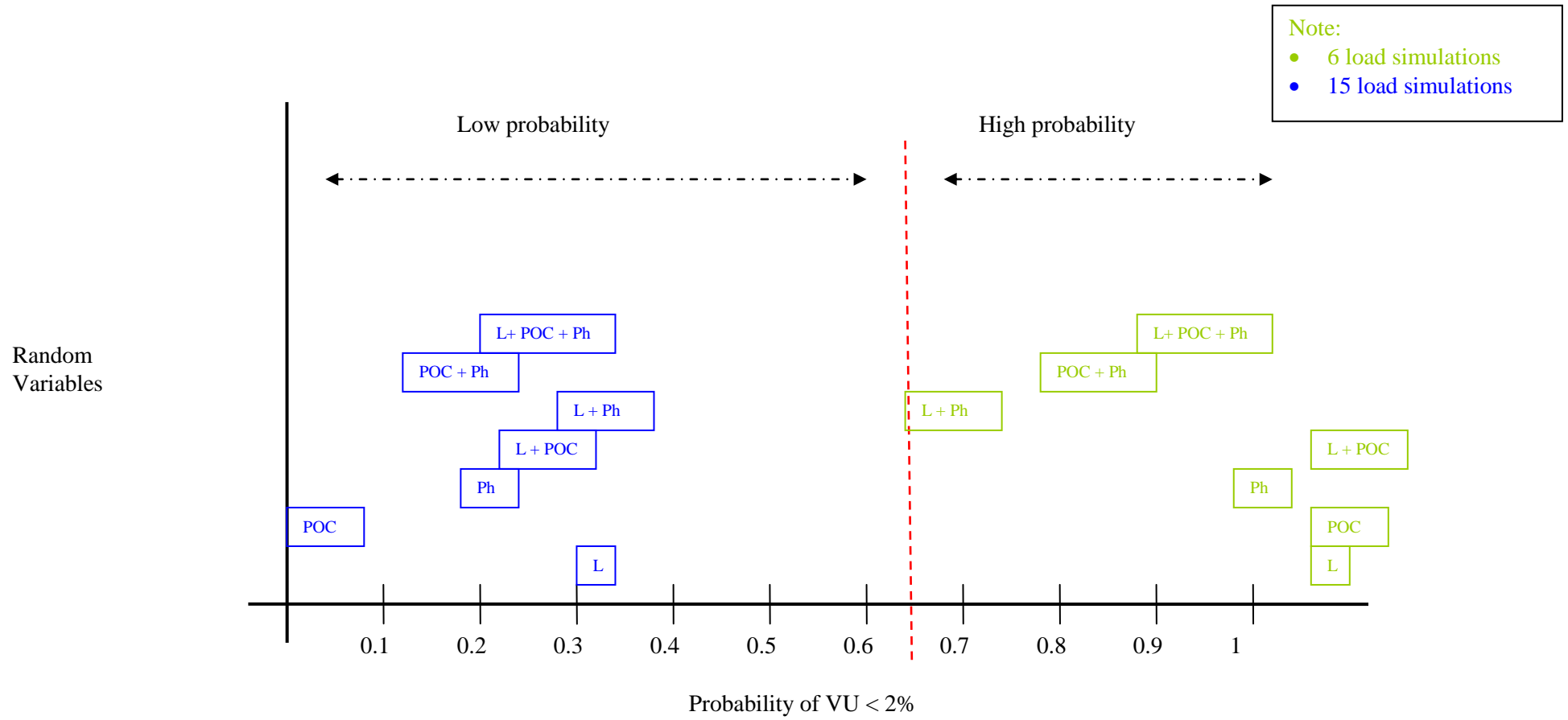


Figure 4-6: Probability of voltage unbalance that is less than 2%

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has investigated both the deterministic and random methods of voltage allocation on feeders with single phase loads. Though the studies were conducted separately, the outcomes reached contribute to the same question of voltage unbalance allocation in general.

The first study, which is based on the deterministic method proposed by IEC, showed that the method proposed is not sufficient for long feeders with single phase loads. The equation similar to that used in the harmonics method proposed in IEC, was derived. Through the use of examples, it was demonstrated that the method can be applied with a high level of confidence by planning engineers. The square root of impedance introduces the necessary line length characteristics required to pinpoint location of load on the feeder. Both the voltage and current limits are restricted to values less than the global allocation.

The second study investigated the probability of archiving a below the limit voltage unbalance while randomly connecting single phase loads on a long rural feeder. The study showed that it is possible to randomly connect single phase loads without exceeding the set limits. However, there are limitations to the size and number of loads that can be connected, whilst adhering to the set limits. Point of connection and phase allocation have a significant impact on unbalance, provided the loads are not significantly different. Phase allocation is easy to solve, but POC is function of where your load centres develop.

5.2 Recommendations

The following are recommendation for applying the method of random connection and allocation:

- Random connection approach can be done if the total number of single phase connections is low i.e. not more than nine connection
- Phase allocation has more influence than the other factors considered. When there is a problem of unbalance on the system, the first parameter the planner needs to alter is phase allocation.
- The second most influential factor is POC. Long lines have a heavy bearing on unbalance.

- Load is consistently changing and therefore not so easy to control. If there are large disparities on maximum demand, it may be necessary to conduct a load flow studies.

5.3 Future research questions

The stochastic nature of system loads will always raise the questions whether utilities are optimising their methods to take advantage of the differentials in the system. The pressure to get more out of less will continue to fuel research in the statistics of power networks. The following are topics suggested based on some of the questions that came out of the study entailed in this dissertation:

- Evaluate the success and failure of the global summation law approach vs the conventional methods.
- The random distribution of load centres, in particular South African network, and the impact on unbalance.

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Appendix A: Symmetrical components

The first definition originates from the theory of symmetrical components which mathematically breaks down an unbalanced system into three balanced systems as shown by Figure 15. These three are called positive sequence, negative and zero sequence systems. For a perfectly balanced system both negative and zero sequence systems would be absent.

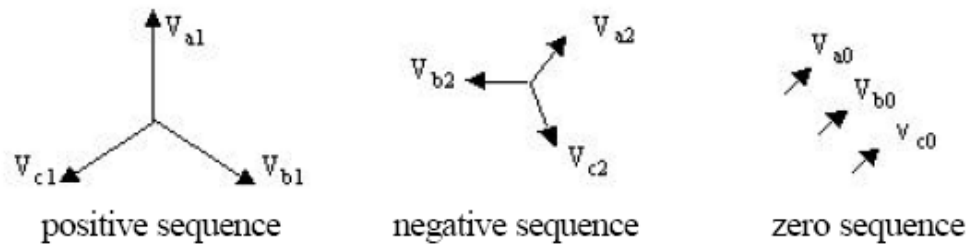


Figure A1 Symmetrical components of an unbalanced system of voltages

The three sequence components can be defined as follows:

- Positive sequence vector is a balanced set of vectors rotating in the same direction as the order of the rotation of the system phase voltages (this vector is given subscript 1);
- Negative sequence vector is a balanced set of vectors rotating in the opposite direction as the order of rotation of the system phase voltages (subscript 2);
- Zero sequence vector is a set of in-phase vectors (subscript 0).

These sequence systems can be given some physical interpretation. The direction of rotation of a three-phase induction motor when applied with a negative sequence set of voltages is opposite to what is obtained when the positive sequence voltages are applied. Having no phase displacement between the three voltages in the zero sequence system, when applied to a three-phase induction motor, it will not rotate at all as there will be no rotating magnetic field.

Appendix B: Visual Basic code

The visual basic code was done in Microsoft Excel. The following figures show the visual interface of the program.

Microsoft Excel - GetSet_15

File Edit View Insert Format Tools Data Window Help

100%

Formulas: =Random Load + POC1C7

Link Show Hide UnLink GetLoad SetLoad

Instructions: 1) Link 2) Show 3) Open File 4) GetLoad 5) SetLoad

Loads

| Node Name | Description | Load1 | Load2 | Load3 | PF1 | PF2 | PF3 | CF | SF | DSP1 | DSP2 | DSP3 | DSP3ph |
|-----------|-------------|--------|--------|--------|-----|-----|-----|----|----|------|------|------|--------|
| LOAD1 | | 363.4 | 363.4 | 363.4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD2 | | 361.99 | 361.99 | 361.99 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD3 | | 300.96 | 300.96 | 300.96 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD4 | | 335.31 | 335.31 | 335.31 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD5 | | 106.49 | 106.49 | 106.49 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD6 | | 153.35 | 153.35 | 153.35 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD7 | | 57.927 | 57.927 | 57.927 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD8 | | 106.83 | 106.83 | 106.83 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD9 | | 213.81 | 213.81 | 213.81 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD10 | | 106.68 | 106.68 | 106.68 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD11 | | 315.3 | 315.3 | 315.3 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD12 | | 203.87 | 203.87 | 203.87 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD13 | | 259.21 | 259.21 | 259.21 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD14 | | 375.45 | 375.45 | 375.45 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| LOAD15 | | 285.37 | 285.37 | 285.37 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

Sum=3545.951294 NUM

Figure B-1: Load tab

Microsoft Excel - GetSet_15

File Edit View Insert Format Tools Data Window Help

100%

Formulas: =Random Load + POC1F7

Link Show Hide UnLink GetBranch SetBranch

Branches

| FromName | ToName | FromDescription | ToDescription | Conductor/Cable | Conductor/Cable Length | UserCode |
|----------|--------|-----------------|---------------|-----------------|------------------------|----------|
| Source_1 | N1 | | | Fox | General | 1012.461 |
| N1 | N2 | | | Fox | General | 1062.141 |
| N2 | N3 | | | Fox | General | 1199.929 |
| N3 | N4 | | | Fox | General | 1174.204 |
| N4 | N5 | | | Fox | General | 1744.544 |
| N5 | N6 | | | Fox | General | 2050.837 |
| N6 | N7 | | | Fox | General | 2178.097 |
| N7 | N8 | | | Fox | General | 3615.902 |
| N8 | N9 | | | Fox | General | 3026.177 |
| N9 | N10 | | | Fox | General | 4799.61 |
| N10 | N11 | | | Fox | General | 3239.621 |
| N11 | N12 | | | Fox | General | 2196.276 |
| N12 | N13 | | | Fox | General | 1663.966 |
| N13 | N14 | | | Fox | General | 1555.505 |
| N14 | N15 | | | Fox | General | 4785.229 |
| N15 | N16 | | | Fox | General | 4399.173 |

Sum=39693.67163 NUM

Figure B-2: Branches tap.

| NodeName | TrfrStr | Primary | Secondary | Iph | Ph | Phase Shift | Int Boost | Load Balance | Z | R | ZO | XR0 | L |
|----------|-----------------------|---------|-----------|-----|----|-------------|-----------|--------------|------|------|------|------|---|
| TRFR1 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | AB | AB | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR2 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | BC | BC | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR3 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | CA | CA | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR4 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | CA | CA | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR5 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | BC | BC | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR6 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | AB | AB | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR7 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | AB | AB | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR8 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | BC | BC | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR9 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | CA | CA | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR10 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | CA | CA | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR11 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | AB | AB | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR12 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | BC | BC | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR13 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | CA | CA | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR14 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | CA | CA | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |
| TRFR15 | 400kVA 22kV/19kV SWER | Ph_Ph | SWER | BC | BC | 0 | 0 | 0 | 5.08 | 3.44 | 5.08 | 3.44 | |

Figure B-3: Transformer tap.

| Node Name | X | Y | Width | Height | Rectangle? | Voltage | Technology | Phase Connection | Phase Allocated | Open | CostStr | AreaCode | Description | NewName |
|-----------|-----|------|-------|--------|------------|---------|------------|------------------|-----------------|-------|---------|----------|-------------|----------|
| Source_1 | 469 | 158 | 30 | 30 | 0 | 19000 | Single | 3P | 3P | FALSE | | | | Source_1 |
| N1 | 468 | 281 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N1 |
| N2 | 467 | 372 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N2 |
| N3 | 467 | 458 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N3 |
| N4 | 465 | 547 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N4 |
| N5 | 465 | 664 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N5 |
| N6 | 464 | 796 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N6 |
| N7 | 464 | 917 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N7 |
| N8 | 464 | 1033 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N8 |
| N9 | 463 | 1155 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N9 |
| N10 | 463 | 1265 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N10 |
| N11 | 463 | 1356 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N11 |
| N12 | 462 | 1451 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N12 |
| N13 | 461 | 1545 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N13 |
| N14 | 461 | 1636 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N14 |
| N15 | 461 | 1714 | 30 | 10 | 1 | 22000 | Star | 3P | 3P | FALSE | | | | N15 |
| TRFR1 | 578 | 304 | 30 | 45 | 1 | 19000 | SWER | AB | AB | FALSE | | | | TRFR1 |
| TRFR2 | 334 | 393 | 30 | 45 | 1 | 19000 | SWER | BC | BC | FALSE | | | | TRFR2 |
| TRFR3 | 595 | 479 | 30 | 45 | 1 | 19000 | SWER | CA | CA | FALSE | | | | TRFR3 |
| TRFR4 | 337 | 570 | 30 | 45 | 1 | 19000 | SWER | CA | CA | FALSE | | | | TRFR4 |
| TRFR5 | 599 | 685 | 30 | 45 | 1 | 19000 | SWER | BC | BC | FALSE | | | | TRFR5 |
| TRFR6 | 332 | 819 | 30 | 45 | 1 | 19000 | SWER | AB | AB | FALSE | | | | TRFR6 |
| TRFR7 | 594 | 939 | 30 | 45 | 1 | 19000 | SWER | AB | AB | FALSE | | | | TRFR7 |
| TRFR8 | 345 | 1055 | 30 | 45 | 1 | 19000 | SWER | BC | BC | FALSE | | | | TRFR8 |
| TRFR9 | 609 | 1134 | 30 | 45 | 1 | 19000 | SWER | CA | CA | FALSE | | | | TRFR9 |
| TRFR10 | 322 | 1244 | 30 | 45 | 1 | 19000 | SWER | CA | CA | FALSE | | | | TRFR10 |
| TRFR11 | 607 | 1376 | 30 | 45 | 1 | 19000 | SWER | AB | AB | FALSE | | | | TRFR11 |
| TRFR12 | 329 | 1473 | 30 | 45 | 1 | 19000 | SWER | BC | BC | FALSE | | | | TRFR12 |

Figure B-4: Nodes tap.

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q |
|----|----------|-------|-------|--------|------------|----|----|------|-------|---|---|----------|---|---|---|---|---|
| 1 | Link | Show | Hide | UnLink | GetResults | | | | | | | | | | | | |
| 2 | Nodes | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | |
| 6 | Source_1 | 100.0 | 100.0 | 100.0 | 55 | 38 | 57 | 0 | 44563 | | 0 | 0.056268 | | | | | |
| 7 | N1 | 97.3 | 97.9 | 96.8 | 83 | 57 | 85 | 2605 | 1989 | | 0 | 0.590333 | | | | | |
| 8 | N2 | 94.7 | 95.9 | 93.7 | 80 | 55 | 85 | 1312 | 1004 | | 0 | 1.273437 | | | | | |
| 9 | N3 | 93.0 | 94.8 | 91.7 | 80 | 47 | 79 | 986 | 755 | | 0 | 1.782318 | | | | | |
| 10 | N4 | 91.1 | 93.4 | 89.6 | 67 | 47 | 65 | 745 | 571 | | 0 | 2.186805 | | | | | |
| 11 | N5 | 89.5 | 92.0 | 87.9 | 56 | 47 | 55 | 602 | 461 | | 0 | 2.364247 | | | | | |
| 12 | N6 | 87.6 | 90.6 | 86.1 | 56 | 41 | 50 | 494 | 379 | | 0 | 2.635783 | | | | | |
| 13 | TRFR1 | 97.6 | 0.0 | 0.0 | 4 | 0 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 14 | TRFR2 | 0.0 | 94.1 | 0.0 | 0 | 10 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 15 | TRFR3 | 0.0 | 0.0 | 90.3 | 0 | 0 | 16 | 0 | 0 | | 0 | 0 | | | | | |
| 16 | TRFR4 | 0.0 | 0.0 | 88.3 | 0 | 0 | 14 | 0 | 0 | | 0 | 0 | | | | | |
| 17 | TRFR5 | 0.0 | 89.6 | 0.0 | 0 | 7 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 18 | TRFR6 | 89.6 | 0.0 | 0.0 | 8 | 0 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 19 | LOAD1 | 97.6 | 0.0 | 0.0 | 4 | 0 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 20 | LOAD4 | 0.0 | 0.0 | 88.3 | 0 | 0 | 14 | 0 | 0 | | 0 | 0 | | | | | |
| 21 | LOAD2 | 0.0 | 94.1 | 0.0 | 0 | 10 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 22 | LOAD3 | 0.0 | 0.0 | 90.3 | 0 | 0 | 16 | 0 | 0 | | 0 | 0 | | | | | |
| 23 | LOAD5 | 0.0 | 89.6 | 0.0 | 0 | 7 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 24 | LOAD6 | 89.6 | 0.0 | 0.0 | 8 | 0 | 0 | 0 | 0 | | 0 | 0 | | | | | |
| 25 | N7 | 86.1 | 89.5 | 84.4 | 51 | 35 | 50 | 422 | 324 | | 0 | 2.967974 | | | | | |
| 26 | N8 | 85.3 | 88.9 | 83.3 | 45 | 28 | 50 | 384 | 295 | | 0 | 3.252591 | | | | | |
| 27 | N9 | 84.8 | 88.7 | 82.7 | 45 | 18 | 42 | 365 | 280 | | 0 | 3.465438 | | | | | |
| 28 | N10 | 84.1 | 88.2 | 81.8 | 34 | 18 | 32 | 333 | 255 | | 0 | 3.716105 | | | | | |
| 29 | N11 | 83.4 | 87.8 | 81.2 | 26 | 16 | 24 | 304 | 233 | | 0 | 3.851554 | | | | | |
| 30 | N12 | 83.1 | 87.5 | 80.4 | 19 | 9 | 24 | 276 | 212 | | 0 | 4.121718 | | | | | |
| 31 | N13 | 82.8 | 87.4 | 79.9 | 19 | 3 | 20 | 259 | 198 | | 0 | 4.363985 | | | | | |
| 32 | N14 | 82.6 | 87.3 | 79.5 | 9 | 3 | 10 | 237 | 182 | | 0 | 4.511167 | | | | | |
| 33 | N15 | 82.6 | 87.2 | 79.5 | 0 | 3 | 3 | 227 | 174 | | 0 | 4.494924 | | | | | |

Figure B-5: Results tap.

The following is the visual basic code:

Private ReticObject As Object

Sub ReticOpen()

Set ReticObject = CreateObject("ReticMaster.App")

End Sub

Sub ShowRetic()

If Not ReticObject Is Nothing Then ReticObject.Show

End Sub

Sub HideRetic()

If Not ReticObject Is Nothing Then ReticObject.Hide

End Sub

Sub ClearRm()

ReticObject.NewFile

End Sub

Sub Link()

Dim MyUserName As String

```
Dim MyPsswr As String
```

```
Dim LI As Integer
```

```
On Error GoTo ErrorHandler
```

```
If ReticObject Is Nothing Then
```

```
    Set ReticObject = CreateObject("ReticMaster.App")
```

```
    If ReticObject.GetSecurityModel = 2 Then
```

```
        If Not ReticObject.IsLoggedIn Then
```

```
            Load frmLogin
```

```
            frmLogin.Show
```

```
            If frmLogin.Tag = 0 Then
```

```
                MyUsrName = frmLogin.edName.Text
```

```
                MyPsswr = frmLogin.edPassword.Text
```

```
                frmLogin.edPassword.Text = ""
```

```
                LI = ReticObject.DoSilentLogin(MyUsrName, MyPsswr)
```

```
            If LI <> 0 Then
```

```
                If ReticObject.DoLogin <> 0 Then
```

```
                    Call UnLink
```

```
                End If
```

```
            End If
```

```
        End If
```

```
        Unload frmLogin
```

```
    End If
```

```
End If
```

```
Exit Sub      ' Exit to avoid handler.
```

```
End If
```

```
ErrorHandler:      ' Error-handling routine.
```

```
Exit Sub

End Sub

Sub UnLink()

    On Error Resume Next

    ReticObject.DoLogoff

    Set ReticObject = Nothing

End Sub

Sub Calc()

    If Not ReticObject Is Nothing Then

        Call SetDomestic

        ReticObject.Calc

        Call Results

    End If

End Sub

Sub ErrorHandler()

    Select Case Err.Number

        Case 91

            MsgBox "Press Create button", vbOKOnly, "RM not linked"

        Case Else

    End Select

End Sub

Sub GetLoad()

    Dim MyVar As Variant

    Dim NodeName As String

    Dim Load1 As Double

    Dim Load2 As Double

    Dim Load3 As Double

    Dim PF1 As Double

    Dim PF2 As Double
```


Dim PF3 As Double

Dim CF As Double

Dim SF As Double

Dim LoadType As String

Dim Description As String

Dim DSP1 As Long

Dim DSP2 As Long

Dim DSP3 As Long

Dim DSPs3ph As Long

If Not ReticObject Is Nothing Then

MyVar = ReticObject.GetNodeNamesListVar

Lower = LBound(MyVar)

Upper = UBound(MyVar)

LoadI = 0

I = Lower

Row = 6

Do

NodeName = MyVar(I)

If ReticObject.GetNodeType(NodeName) = "LOAD" Then

ReticObject.GetLoad NodeName, Load1, Load2, Load3, PF1, PF2, PF3, CF, SF, LoadType

ReticObject.GetDSPs NodeName, DSP1, DSP2, DSP3

ReticObject.GetDSPs3ph NodeName, DSPs3ph

TotLoad = Load1 + Load2 + Load3 + DSP1 + DSP2 + DSP3 + DSPs3ph

If TotLoad > 0 Then

ReticObject.GetDescription NodeName, Description

```
Worksheets("Loads").Cells(Row, 1).Value = NodeName
Worksheets("Loads").Cells(Row, 2).Value = Description
Worksheets("Loads").Cells(Row, 3).Value = Load1
Worksheets("Loads").Cells(Row, 4).Value = Load2
Worksheets("Loads").Cells(Row, 5).Value = Load3
Worksheets("Loads").Cells(Row, 6).Value = PF1
Worksheets("Loads").Cells(Row, 7).Value = PF2
Worksheets("Loads").Cells(Row, 8).Value = PF3
Worksheets("Loads").Cells(Row, 9).Value = CF
Worksheets("Loads").Cells(Row, 10).Value = SF
Worksheets("Loads").Cells(Row, 11).Value = DSP1
Worksheets("Loads").Cells(Row, 12).Value = DSP2
Worksheets("Loads").Cells(Row, 13).Value = DSP3
Worksheets("Loads").Cells(Row, 14).Value = DSPs3ph

Row = Row + 1

End If

End If

I = I + 1

Loop While I <= Upper

End If

End Sub

Sub SetLoad()

Dim NodeName As String

Dim Load1 As Double

Dim Load2 As Double

Dim Load3 As Double

Dim PF1 As Double

Dim PF2 As Double

Dim PF3 As Double
```

Dim CF As Double

Dim SF As Double

Dim LoadType As String

Dim Description As String

Dim DSP1 As Long

Dim DSP2 As Long

Dim DSP3 As Long

Dim DSPs3ph As Long

If Not ReticObject Is Nothing Then

Row = 6

Do

NodeName = Worksheets("Loads").Cells(Row, 1).Value

Load1 = Worksheets("Loads").Cells(Row, 3).Value

Load2 = Worksheets("Loads").Cells(Row, 4).Value

Load3 = Worksheets("Loads").Cells(Row, 5).Value

PF1 = Worksheets("Loads").Cells(Row, 6).Value

PF2 = Worksheets("Loads").Cells(Row, 7).Value

PF3 = Worksheets("Loads").Cells(Row, 8).Value

CF = Worksheets("Loads").Cells(Row, 9).Value

SF = Worksheets("Loads").Cells(Row, 10).Value

DSP1 = Worksheets("Loads").Cells(Row, 11).Value

DSP2 = Worksheets("Loads").Cells(Row, 12).Value

DSP3 = Worksheets("Loads").Cells(Row, 13).Value

DSPs3ph = Worksheets("Loads").Cells(Row, 14).Value

If Len(NodeName) > 0 Then

ReticObject.SetLoad NodeName, Load1, Load2, Load3, PF1, PF2, PF3, CF, SF, LoadType

ReticObject.SetDSPs NodeName, DSP1, DSP2, DSP3

ReticObject.SetDSPs3ph NodeName, DSPs3ph

```
End If

Row = Row + 1

Loop While Len(NodeName) > 0

ReticObject.Calc

End If

End Sub

Sub GetBranch()

Dim MyVar As Variant

Dim ToNodeName As String

Dim FromNodeName As String

Dim ToNodeDescription As String

Dim FromNodeDescription As String

Dim ConName As String

Dim ConGroup As String

Dim UserCode As String

Dim ConLen As Double

If Not ReticObject Is Nothing Then

MyVar = ReticObject.GetNodeNamesListVar

Lower = LBound(MyVar)

Upper = UBound(MyVar)

I = Lower

Row = 6

Do

ToNodeName = MyVar(I)

If ReticObject.GetNodeType(ToNodeName) = "LOAD" Then

FromNodeName = ReticObject.GetFromNodeName(ToNodeName)
```

If FromNodeName <> "" Then

FromNodeName = Mid(FromNodeName, 2, Len(FromNodeName) - 2)

ReticObject.GetDescription ToNodeName, ToNodeDescription

ReticObject.GetDescription FromNodeName, FromNodeDescription

ReticObject.GetConductor2008 ToNodeName, ConName, ConGroup, UserCode, ConLen

End If

If ConName <> "SWCH" Then

Worksheets("Branches").Cells(Row, 1).Value = FromNodeName

Worksheets("Branches").Cells(Row, 2).Value = ToNodeName

Worksheets("Branches").Cells(Row, 3).Value = FromNodeDescription

Worksheets("Branches").Cells(Row, 4).Value = ToNodeDescription

Worksheets("Branches").Cells(Row, 5).Value = ConName

Worksheets("Branches").Cells(Row, 6).Value = ConGroup

Worksheets("Branches").Cells(Row, 7).Value = ConLen

Worksheets("Branches").Cells(Row, 8).Value = UserCode

Row = Row + 1

End If

End If

I = I + 1

Loop While I <= Upper

End If

End Sub

Sub SetBranch()

Dim ToNodeName As String

Dim FromNodeName As String

Dim ToNodeDescription As String

Dim FromNodeDescription As String

Dim ConName As String

Dim ConGroup As String

Dim ConLen As Double

Dim UCode As String

If Not ReticObject Is Nothing Then

Row = 6

Do

FromNodeName = Worksheets("Branches").Cells(Row, 1).Value

ToNodeName = Worksheets("Branches").Cells(Row, 2).Value

FromNodeDescription = Worksheets("Branches").Cells(Row, 3).Value

ToNodeDescription = Worksheets("Branches").Cells(Row, 4).Value

ConName = Worksheets("Branches").Cells(Row, 5).Value

ConGroup = Worksheets("Branches").Cells(Row, 6).Value

ConLen = Worksheets("Branches").Cells(Row, 7).Value

UCode = Worksheets("Branches").Cells(Row, 8).Value

If Len(ToNodeName) > 0 Then

End If

ReticObject.SetConductor2008 ToNodeName, ConName, ConGroup, UCode, ConLen, False

Row = Row + 1

Loop While Len(ToNodeName) > 0

ReticObject.Calc

End If

End Sub

Sub GetTrfr()

Dim MyVar As Variant

Dim NodeName As String

Dim NameStr As String

Dim TrfrStr As String

Dim IPhaseStr As String

Dim PhaseStr As String

Dim PrimStr As String

Dim SecStr As String

Dim PhaseShift As Double

Dim InternalBoost As Double

Dim LoadBalance As Long

Dim Impedance As Double

Dim XR As Double

Dim Impedance0 As Double

Dim XR0 As Double

Dim OL As Double

Dim PhysicalTap As Boolean

Dim TapSetA As Double

Dim TapSetB As Double

Dim TapStep As Double

Dim TapPos As Double

Dim TapVMin As Double

Dim TapVMax As Double

Dim LockedTap As Boolean

Dim ILossW As Double

Dim ILossVar As Double

Dim StatusOpen As Boolean

Dim PrimGrounded As Boolean

Dim SecGrounded As Boolean

Dim ZpR0 As Double

Dim ZpX0 As Double

Dim ZsR0 As Double

Dim ZsX0 As Double

Dim Regulator As Boolean

Dim PrimrStar As Boolean

Dim OpenDelta As Boolean

Dim CostStr As String

Dim AreaCode As String

Dim Description As String

Dim UserCode As String

Dim DomesticLoadCategory As String

Worksheets("Transformers").Activate

Range("A6:AK65536").Select

Selection.ClearContents

Range("A6").Select

If Not ReticObject Is Nothing Then

 MyVar = ReticObject.GetNodeNamesListVar

 Lower = LBound(MyVar)

 Upper = UBound(MyVar)

 If Upper = -1 Then

 GoTo GetTrfrEnd

 End If

 I = Lower

 Row = 6

 Do

 NodeName = MyVar(I)

 If ReticObject.GetNodeType(NodeName) = "TRFR" Then

 ReticObject.GetTrfrData2008 NodeName, TrfrStr, PrimStr, SecStr, IPhaseStr, PhaseStr, _

 PhaseShift, InternalBoost, LoadBalance, Impedance, XR, Impedance0, XR0,
OL, _

 PhysicalTap, TapSetA, TapSetB, TapStep, TapPos, TapVMax, TapVMin,
LockedTap, _

ILossW, ILossVar, StatusOpen, PrimGrounded, SecGrounded, ZpR0, ZpX0,
ZsR0, ZsX0, Regulator, _

CostStr, AreaCode, Description, UserCode, DomesticLoadCategory

Worksheets("Transformers").Cells(Row, 1).Value = NodeName

Worksheets("Transformers").Cells(Row, 2).Value = TrfrStr

Worksheets("Transformers").Cells(Row, 3).Value = PrimStr

Worksheets("Transformers").Cells(Row, 4).Value = SecStr

Worksheets("Transformers").Cells(Row, 5).Value = IPhaseStr

Worksheets("Transformers").Cells(Row, 6).Value = PhaseStr

Worksheets("Transformers").Cells(Row, 7).Value = PhaseShift

Worksheets("Transformers").Cells(Row, 8).Value = InternalBoost

Worksheets("Transformers").Cells(Row, 9).Value = LoadBalance

Worksheets("Transformers").Cells(Row, 10).Value = Impedance

Worksheets("Transformers").Cells(Row, 11).Value = XR

Worksheets("Transformers").Cells(Row, 12).Value = Impedance0

Worksheets("Transformers").Cells(Row, 13).Value = XR0

Worksheets("Transformers").Cells(Row, 14).Value = OL

Worksheets("Transformers").Cells(Row, 15).Value = PhysicalTap

Worksheets("Transformers").Cells(Row, 16).Value = TapSetA

Worksheets("Transformers").Cells(Row, 17).Value = TapSetB

Worksheets("Transformers").Cells(Row, 18).Value = TapStep

Worksheets("Transformers").Cells(Row, 19).Value = TapPos

Worksheets("Transformers").Cells(Row, 20).Value = TapVMax

Worksheets("Transformers").Cells(Row, 21).Value = TapVMin

Worksheets("Transformers").Cells(Row, 22).Value = LockedTap

Worksheets("Transformers").Cells(Row, 23).Value = ILossW

Worksheets("Transformers").Cells(Row, 24).Value = ILossVar

Worksheets("Transformers").Cells(Row, 25).Value = StatusOpen

Worksheets("Transformers").Cells(Row, 26).Value = PrimGrounded

Worksheets("Transformers").Cells(Row, 27).Value = SecGrounded

Worksheets("Transformers").Cells(Row, 28).Value = ZpR0

Worksheets("Transformers").Cells(Row, 29).Value = ZpX0

Worksheets("Transformers").Cells(Row, 30).Value = ZsR0

Worksheets("Transformers").Cells(Row, 31).Value = ZsX0

Worksheets("Transformers").Cells(Row, 32).Value = Regulator

Worksheets("Transformers").Cells(Row, 33).Value = CostStr

Worksheets("Transformers").Cells(Row, 34).Value = AreaCode

Worksheets("Transformers").Cells(Row, 35).Value = Description

Worksheets("Transformers").Cells(Row, 36).Value = UserCode

Worksheets("Transformers").Cells(Row, 37).Value = DomesticLoadCategory

Row = Row + 1

End If

I = I + 1

Loop While I <= Upper

GetTrfrEnd:

End If

End Sub

Sub SetTrfr()

Dim MyVar As Variant

Dim NodeName As String

Dim TrfrStr As String

Dim IPhaseStr As String

Dim PhaseStr As String

Dim PrimStr As String

Dim SecStr As String

Dim PhaseShift As Double

Dim InternalBoost As Double

Dim LoadBalance As Long

Dim Impedance As Double

Dim XR As Double

Dim Impedance0 As Double

Dim XR0 As Double

Dim OL As Double

Dim PhysicalTap As Boolean

Dim TapSetA As Double

Dim TapSetB As Double

Dim TapStep As Double

Dim TapPos As Double

Dim TapVMin As Double

Dim TapVMax As Double

Dim LockedTap As Boolean

Dim ILossW As Double

Dim ILossVar As Double

Dim StatusOpen As Boolean

Dim PrimGrounded As Boolean

Dim SecGrounded As Boolean

Dim ZpR0 As Double

Dim ZpX0 As Double

Dim ZsR0 As Double

Dim ZsX0 As Double

Dim Regulator As Boolean

Dim PrimrStar As Boolean

Dim OpenDelta As Boolean

Dim CostStr As String

Dim AreaCode As String

Dim Description As String

Dim UserCode As String

Dim DomesticLoadCategory As String

If Not ReticObject Is Nothing Then

Row = 6

Do

NodeName = Worksheets("Transformers").Cells(Row, 1).Value

TrfrStr = Worksheets("Transformers").Cells(Row, 2).Value

ReticObject.GetTrfrData2008 NodeName, TrfrStr, PrimStr, SecStr, IPhaseStr, PhaseStr, _
OL, _
PhaseShift, InternalBoost, LoadBalance, Impedance, XR, Impedance0, XR0,
LockedTap, _
PhysicalTap, TapSetA, TapSetB, TapStep, TapPos, TapVMax, TapVMin,
ILossW, ILossVar, StatusOpen, PrimGrounded, SecGrounded, ZpR0, ZpX0,
ZsR0, ZsX0, Regulator, _
CostStr, AreaCode, Description, UserCode, DomesticLoadCategory

TrfrStr = Worksheets("Transformers").Cells(Row, 2).Value

PrimStr = Worksheets("Transformers").Cells(Row, 3).Value

SecStr = Worksheets("Transformers").Cells(Row, 4).Value

IPhaseStr = Worksheets("Transformers").Cells(Row, 5).Value

PhaseStr = Worksheets("Transformers").Cells(Row, 6).Value

PhaseShift = Worksheets("Transformers").Cells(Row, 7).Value

InternalBoost = Worksheets("Transformers").Cells(Row, 8).Value

LoadBalance = Worksheets("Transformers").Cells(Row, 9).Value

Impedance = Worksheets("Transformers").Cells(Row, 10).Value

XR = Worksheets("Transformers").Cells(Row, 11).Value

Impedance0 = Worksheets("Transformers").Cells(Row, 12).Value

XR0 = Worksheets("Transformers").Cells(Row, 13).Value

OL = Worksheets("Transformers").Cells(Row, 14).Value
PhysicalTap = Worksheets("Transformers").Cells(Row, 15).Value
TapSetA = Worksheets("Transformers").Cells(Row, 16).Value
TapSetB = Worksheets("Transformers").Cells(Row, 17).Value
TapStep = Worksheets("Transformers").Cells(Row, 18).Value
TapPos = Worksheets("Transformers").Cells(Row, 19).Value
TapVMax = Worksheets("Transformers").Cells(Row, 20).Value
TapVMin = Worksheets("Transformers").Cells(Row, 21).Value
LockedTap = Worksheets("Transformers").Cells(Row, 22).Value
ILossW = Worksheets("Transformers").Cells(Row, 23).Value
ILossVar = Worksheets("Transformers").Cells(Row, 24).Value
StatusOpen = Worksheets("Transformers").Cells(Row, 25).Value
PrimGrounded = Worksheets("Transformers").Cells(Row, 26).Value
SecGrounded = Worksheets("Transformers").Cells(Row, 27).Value
ZpR0 = Worksheets("Transformers").Cells(Row, 28).Value
ZpX0 = Worksheets("Transformers").Cells(Row, 29).Value
ZsR0 = Worksheets("Transformers").Cells(Row, 30).Value
ZsX0 = Worksheets("Transformers").Cells(Row, 31).Value
Regulator = Worksheets("Transformers").Cells(Row, 32).Value
CostStr = Worksheets("Transformers").Cells(Row, 33).Value
AreaCode = Worksheets("Transformers").Cells(Row, 34).Value
Description = Worksheets("Transformers").Cells(Row, 35).Value
UserCode = Worksheets("Transformers").Cells(Row, 36).Value
DomesticLoadCategory = Worksheets("Transformers").Cells(Row, 37).Value

ReticObject.setTrfrData2008 NodeName, TrfrStr, PrimStr, SecStr, IPhaseStr, PhaseStr, _
PhaseShift, InternalBoost, LoadBalance, Impedance, XR, Impedance0, XR0,
OL, _
PhysicalTap, TapSetA, TapSetB, TapStep, TapPos, TapVMax, TapVMin,
LockedTap, _

ILossW, ILossVar, StatusOpen, PrimGrounded, SecGrounded, ZpR0, ZpX0,
ZsR0, ZsX0, Regulator, _

CostStr, AreaCode, Description, UserCode, DomesticLoadCategory

Row = Row + 1

Loop While Len(NodeName) > 0

ReticObject.Calc

End If

End Sub

Sub GetMotor()

Dim NomVoltage As Double

Dim ConductorStr As String

Dim TechnologyType As String

Dim PhaseStr As String

Dim ConductorLength As Double

Dim Load1 As Double

Dim Load2 As Double

Dim Load3 As Double

Dim PF1 As Double

Dim PF2 As Double

Dim PF3 As Double

Dim CF As Double

Dim SF As Double

Dim StatusOpen As Boolean

Dim CostStr As String

Dim LoadCategory As String

Dim MotorCategory As String

Dim AreaCode As String

Dim Description As String

Dim MyVar As Variant

Dim NodeName As String

If Not ReticObject Is Nothing Then

MyVar = ReticObject.GetNodeNamesListVar

Lower = LBound(MyVar)

Upper = UBound(MyVar)

I = Lower

Row = 6

Do

 NodeName = MyVar(I)

 If ReticObject.GetNodeType(NodeName) = "MOTOR" Then

 ReticObject.GetMotorData NodeName, NomVoltage, ConductorStr, TechnologyType,
 PhaseStr, ConductorLength, _

 Load1, Load2, Load3, PF1, PF2, PF3, CF, SF, StatusOpen, CostStr, LoadCategory, _

 MotorCategory, AreaCode, Description

Worksheets("GetSet").Cells(Row, 35).Value = NodeName

Worksheets("GetSet").Cells(Row, 36).Value = NomVoltage

Worksheets("GetSet").Cells(Row, 37).Value = ConductorStr

Worksheets("GetSet").Cells(Row, 38).Value = TechnologyType

Worksheets("GetSet").Cells(Row, 39).Value = PhaseStr

Worksheets("GetSet").Cells(Row, 40).Value = ConductorLength

Worksheets("GetSet").Cells(Row, 41).Value = Load1

Worksheets("GetSet").Cells(Row, 42).Value = Load2

```
Worksheets("GetSet").Cells(Row, 43).Value = Load3  
Worksheets("GetSet").Cells(Row, 44).Value = PF1  
Worksheets("GetSet").Cells(Row, 45).Value = PF2  
Worksheets("GetSet").Cells(Row, 46).Value = PF3  
Worksheets("GetSet").Cells(Row, 47).Value = CF  
Worksheets("GetSet").Cells(Row, 48).Value = SF  
Worksheets("GetSet").Cells(Row, 49).Value = StatusOpen  
Worksheets("GetSet").Cells(Row, 50).Value = CostStr  
Worksheets("GetSet").Cells(Row, 51).Value = LoadCategory  
Worksheets("GetSet").Cells(Row, 52).Value = MotorCategory  
Worksheets("GetSet").Cells(Row, 53).Value = AreaCode  
Worksheets("GetSet").Cells(Row, 54).Value = Description
```

```
Row = Row + 1
```

```
End If
```

```
I = I + 1
```

```
Loop While I <= Upper
```

```
End If
```

```
End Sub
```

```
Sub GetNode()
```

```
Dim X As Long
```

```
Dim Y As Long
```

```
Dim W As Long
```

```
Dim H As Long
```

```
Dim R As Long
```

```
Dim NomVoltage As Double
```

```
Dim ConductorStr As String
```


Dim TechnologyType As String

Dim IPhaseStr As String

Dim PhaseStr As String

Dim StatusOpen As Boolean

Dim CostStr As String

Dim AreaCode As String

Dim Description As String

Dim MyVar As Variant

Dim NodeName As String

Dim NodeType As String

If Not ReticObject Is Nothing Then

 MyVar = ReticObject.GetNodeNamesListVar

 Lower = LBound(MyVar)

 Upper = UBound(MyVar)

 I = Lower

 Row = 6

 Do

 NodeName = MyVar(I)

 NodeType = ReticObject.GetNodeType(NodeName)

 If NodeType <> "TEXT" Then

 ReticObject.GetNodeData2008 NodeName, X, Y, W, H, R, _

 NomVoltage, TechnologyType, IPhaseStr, PhaseStr, _

 StatusOpen, CostStr, AreaCode, Description

 Worksheets("Nodes").Cells(Row, 1).Value = NodeName

 Worksheets("Nodes").Cells(Row, 2).Value = X

```
Worksheets("Nodes").Cells(Row, 3).Value = Y
Worksheets("Nodes").Cells(Row, 4).Value = W
Worksheets("Nodes").Cells(Row, 5).Value = H
Worksheets("Nodes").Cells(Row, 6).Value = R
Worksheets("Nodes").Cells(Row, 7).Value = NomVoltage
Worksheets("Nodes").Cells(Row, 8).Value = TechnologyType
Worksheets("Nodes").Cells(Row, 9).Value = IPhaseStr
Worksheets("Nodes").Cells(Row, 10).Value = PhaseStr
Worksheets("Nodes").Cells(Row, 11).Value = StatusOpen
Worksheets("Nodes").Cells(Row, 12).Value = CostStr
Worksheets("Nodes").Cells(Row, 13).Value = AreaCode
Worksheets("Nodes").Cells(Row, 14).Value = Description
Worksheets("Nodes").Cells(Row, 15).Value = NodeName

Row = Row + 1

End If

I = I + 1

Loop While I <= Upper

End If

End Sub

Sub SetNode()

Dim X As Long

Dim Y As Long

Dim W As Long

Dim H As Long

Dim R As Long

Dim NomVoltage As Double

Dim ConductorStr As String

Dim TechnologyType As String

Dim PhaseStr As String

Dim StatusOpen As Boolean
```

Dim CostStr As String

Dim AreaCode As String

Dim Description As String

Dim MyVar As Variant

Dim NodeName As String

Dim NodeType As String

Dim NewName As String

If Not ReticObject Is Nothing Then

Row = 6

Do

NodeName = Worksheets("Nodes").Cells(Row, 1).Value

X = Worksheets("Nodes").Cells(Row, 2).Value

Y = Worksheets("Nodes").Cells(Row, 3).Value

W = Worksheets("Nodes").Cells(Row, 4).Value

H = Worksheets("Nodes").Cells(Row, 5).Value

R = Worksheets("Nodes").Cells(Row, 6).Value

NomVoltage = Worksheets("Nodes").Cells(Row, 7).Value

TechnologyType = Worksheets("Nodes").Cells(Row, 8).Value

IPhaseStr = Worksheets("Nodes").Cells(Row, 9).Value

PhaseStr = Worksheets("Nodes").Cells(Row, 10).Value

StatusOpen = Worksheets("Nodes").Cells(Row, 11).Value

CostStr = Worksheets("Nodes").Cells(Row, 12).Value

AreaCode = Worksheets("Nodes").Cells(Row, 13).Value

Description = Worksheets("Nodes").Cells(Row, 14).Value

NewName = Worksheets("Nodes").Cells(Row, 15).Value

If Len(NodeName) > 0 Then

ReticObject.SetNodeData2008 NodeName, X, Y, W, H, R, _

```

        NomVoltage, TechnologyType, IPhaseStr, PhaseStr, _
        StatusOpen, CostStr, AreaCode, Description
    If Len(NewName) > 0 Then
        ReticObject.ChangeName NodeName, NewName
    End If
End If

    Row = Row + 1

    Loop While Len(NodeName) > 0

        ReticObject.Calc

    End If
End Sub

Sub GetNodeResults()

    Dim Dist As Double

    Dim TrfrName As String

    Dim MyVar As Variant

    Dim NodeName As String

    Dim NodeType As String

    Dim PhPhFlag As Boolean

    Dim VBase As Double

    Dim Va As Double

    Dim VaAngle As Double

    Dim Vb As Double

    Dim VbAngle As Double

    Dim Vc As Double

    Dim VcAngle As Double

    Dim Ia As Double

    Dim IaAngle As Double

    Dim Ib As Double

    Dim IbAngle As Double
```

Dim Ic As Double

Dim IcAngle As Double

Dim FI3Ph As Double

Dim FLPhN As Double

Dim FLPhG As Double

Dim FLPhPh As Double

Dim FIPhPhG As Double

Dim FI3PhAngle As Double

Dim FLPhNAngle As Double

Dim FLPhGAngle As Double

Dim FLPhPhAngle As Double

Dim FIPhPhGAngle As Double

Dim TotDSP As Double

Dim TotLoadP As Double

Dim TotLoadQ As Double

Dim TotLossP As Double

Dim TotLossQ As Double

Dim TotEnergy As Double

Dim TotLossEnergy As Double

Dim VSeqPos As Double

Dim VSeqNeg As Double

Dim VSeqZero As Double

Dim FromName As String

Dim TempStr As String

Dim L As Long

If Not ReticObject Is Nothing Then

 Rows("6:65536").Select

 Selection.ClearContents

 Range("A6").Select

```
MyVar = ReticObject.GetNodeNamesListVar
```

```
Lower = LBound(MyVar)
```

```
Upper = UBound(MyVar)
```

```
I = Lower
```

```
Row = 6
```

```
Do
```

```
    NodeName = MyVar(I)
```

```
    NodeType = ReticObject.GetNodeType(NodeName)
```

```
    PhPhFlag = False
```

```
    ReticObject.GetNodeResults NodeName, PhPhFlag, VBase, Va, VaAngle, Vb, VbAngle, Vc,  
    VcAngle, _
```

```
        Ia, IaAngle, Ib, IbAngle, Ic, IcAngle, Fl3Ph, FLPhN, FLPhG, FLPhPh, _
```

```
        FlPhPhG, Fl3PhAngle, FLPhNAngle, FLPhGAngle, FLPhPhAngle, FlPhPhGAngle, _
```

```
        TotDSP, TotLoadP, TotLoadQ, TotLossP, TotLossQ, TotEnergy, TotLossEnergy, _
```

```
        VSeqPos, VSeqNeg, VSeqZero
```

```
Worksheets("NodeResults").Cells(Row, 1).Value = NodeName
```

```
Worksheets("NodeResults").Cells(Row, 2).Value = Va
```

```
Worksheets("NodeResults").Cells(Row, 3).Value = Vb
```

```
Worksheets("NodeResults").Cells(Row, 4).Value = Vc
```

```
Worksheets("NodeResults").Cells(Row, 5).Value = Ia
```

```
Worksheets("NodeResults").Cells(Row, 6).Value = Ib
```

```
Worksheets("NodeResults").Cells(Row, 7).Value = Ic
```

```
Worksheets("NodeResults").Cells(Row, 8).Value = Fl3Ph
```

```
Worksheets("NodeResults").Cells(Row, 9).Value = FLPhG
```

```
Worksheets("NodeResults").Cells(Row, 12).Value = VSeqNeg
```

```
TrfrName = ""

FromName = ReticObject.GetFromNodeName(NodeName)

If FromName <> "" Then

    FromName = VBA.Mid(FromName, 2, VBA.Len(FromName) - 2)

End If

Do

    If ReticObject.GetNodeType(FromName) = "TRFR" Then

        TrfrName = FromName

    End If

    FromName = ReticObject.GetFromNodeName(FromName)

    If FromName <> "" Then

        FromName = VBA.Mid(FromName, 2, VBA.Len(FromName) - 2)

    End If

Loop While FromName <> "" And TrfrName = ""

Dist = 0

If TrfrName <> "" Then

    Dist = ReticObject.GetDistance(TrfrName, NodeName)

End If

Worksheets("NodeResults").Cells(Row, 10).Value = TrfrName

Worksheets("NodeResults").Cells(Row, 11).Value = Dist

Row = Row + 1

I = I + 1

Loop While I <= Upper

End If

End Sub

Sub GetRegulatorData()

    Dim MyVar As Variant

    Dim NodeName As String
```

Dim RegulatorStr As String

Dim PhaseStr As String

Dim Configuration As Long

Dim Direction As Long

Dim SeriesWinding As Long

Dim Impedance As Double

Dim XR As Double

Dim IronLoss As Double

Dim InternalBoost As Boolean

Dim PosPhaseRotation As Boolean

Dim VSet As Double

Dim VBand As Double

Dim TapPos1 As Long

Dim TapPos2 As Long

Dim TapPos3 As Long

Dim LockTap1 As Boolean

Dim LockTap2 As Boolean

Dim LockTap3 As Boolean

Dim GangTap As Boolean

Dim UseLDC As Boolean

Dim StatusOpen As Boolean

Dim CTRating As Double

Dim VTRatio As Double

Dim Vmin As Double

Dim Vmax As Double

Dim RLDC As Double

Dim XLDC As Double

Dim RnLDC As Double

Dim XnLDC As Double

Dim Distance As Double

Dim Temperature As Double

Dim ConductorStr As String

Dim UserCodeStr As String

If Not ReticObject Is Nothing Then

MyVar = ReticObject.GetNodeNamesListVar

Lower = LBound(MyVar)

Upper = UBound(MyVar)

I = Lower

Row = 6

Col = 1

Do

NodeName = MyVar(I)

NodeType = ReticObject.GetNodeType(NodeName)

If ReticObject.GetNodeType(NodeName) = "REGULATOR" Then

ReticObject.GetRegulatorDataEx NodeName, _

RegulatorStr, PhaseStr, _

Configuration, Direction, SeriesWinding, _

Impedance, XR, IronLoss, _

InternalBoost, PosPhaseRotation, _

VSet, VBand, _

TapPos1, TapPos2, TapPos3, _

LockTap1, LockTap2, LockTap3, GangTap, UseLDC, StatusOpen, _

Distance, Temperature, _

ConductorStr, UserCodeStr

Worksheets("Regulators").Cells(Row, Col).Value = NodeName

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = RegulatorStr

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = PhaseStr

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Configuration

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Direction

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = SeriesWinding

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Impedance

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = XR

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = IronLoss

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = InternalBoost

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = PosPhaseRotation

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = VSet

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = VBand

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = TapPos1

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = TapPos2

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = TapPos3

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = LockTap1

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = LockTap2

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = LockTap3

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = GangTap

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = UseLDC

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = StatusOpen

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = CTRating

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = VTRatio

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Vmin

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Vmax

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = RLDC

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = XLDC

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = RnLDC

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = XnLDC

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Distance

```
Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = Temperature

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = ConductorStr

Col = Col + 1

Worksheets("Regulators").Cells(Row, Col).Value = UserCodeStr

Row = Row + 1

End If

I = I + 1

Col = 1

Loop While I <= Upper

End If

End Sub

Sub SetRegulatorData()

Dim MyVar As Variant

Dim NodeName As String

Dim RegulatorStr As String

Dim PhaseStr As String

Dim Configuration As Long

Dim Direction As Long

Dim SeriesWinding As Long

Dim Impedance As Double

Dim XR As Double

Dim IronLoss As Double

Dim InternalBoost As Boolean

Dim PosPhaseRotation As Boolean

Dim VSet As Double

Dim VBand As Double

Dim TapPos1 As Long
```

Dim TapPos2 As Long

Dim TapPos3 As Long

Dim LockTap1 As Boolean

Dim LockTap2 As Boolean

Dim LockTap3 As Boolean

Dim GangTap As Boolean

Dim UseLDC As Boolean

Dim StatusOpen As Boolean

Dim CTRating As Double

Dim VTRatio As Double

Dim Vmin As Double

Dim Vmax As Double

Dim RLDC As Double

Dim XLDC As Double

Dim RnLDC As Double

Dim XnLDC As Double

Dim Distance As Double

Dim Temperature As Double

Dim ConductorStr As String

Dim UserCodeStr As String

If Not ReticObject Is Nothing Then

Row = 6

Col = 1

Do

NodeName = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

RegulatorStr = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

PhaseStr = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Configuration = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Direction = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

SeriesWinding = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Impedance = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

XR = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

IronLoss = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

InternalBoost = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

PosPhaseRotation = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

VSet = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

VBand = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

TapPos1 = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

TapPos2 = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

TapPos3 = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

LockTap1 = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

LockTap2 = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

LockTap3 = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

GangTap = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

UseLDC = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

StatusOpen = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

CTRating = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

VTRatio = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Vmin = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Vmax = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

RLDC = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

XLDC = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

RnLDC = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

XnLDC = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Distance = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

Temperature = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

ConductorStr = Worksheets("Regulators").Cells(Row, Col).Value

Col = Col + 1

UserCodeStr = Worksheets("Regulators").Cells(Row, Col).Value

Row = Row + 1

Col = 1

ReticObject.SetRegulatorDataEx NodeName, _

RegulatorStr, PhaseStr, _

Configuration, Direction, SeriesWinding, _

Impedance, XR, IronLoss, _

InternalBoost, PosPhaseRotation, _

VSet, VBand, _

TapPos1, TapPos2, TapPos3, _

LockTap1, LockTap2, LockTap3, GangTap, UseLDC, StatusOpen, _

Distance, Temperature, _

ConductorStr, UserCodeStr

Loop While Len(NodeName) > 0

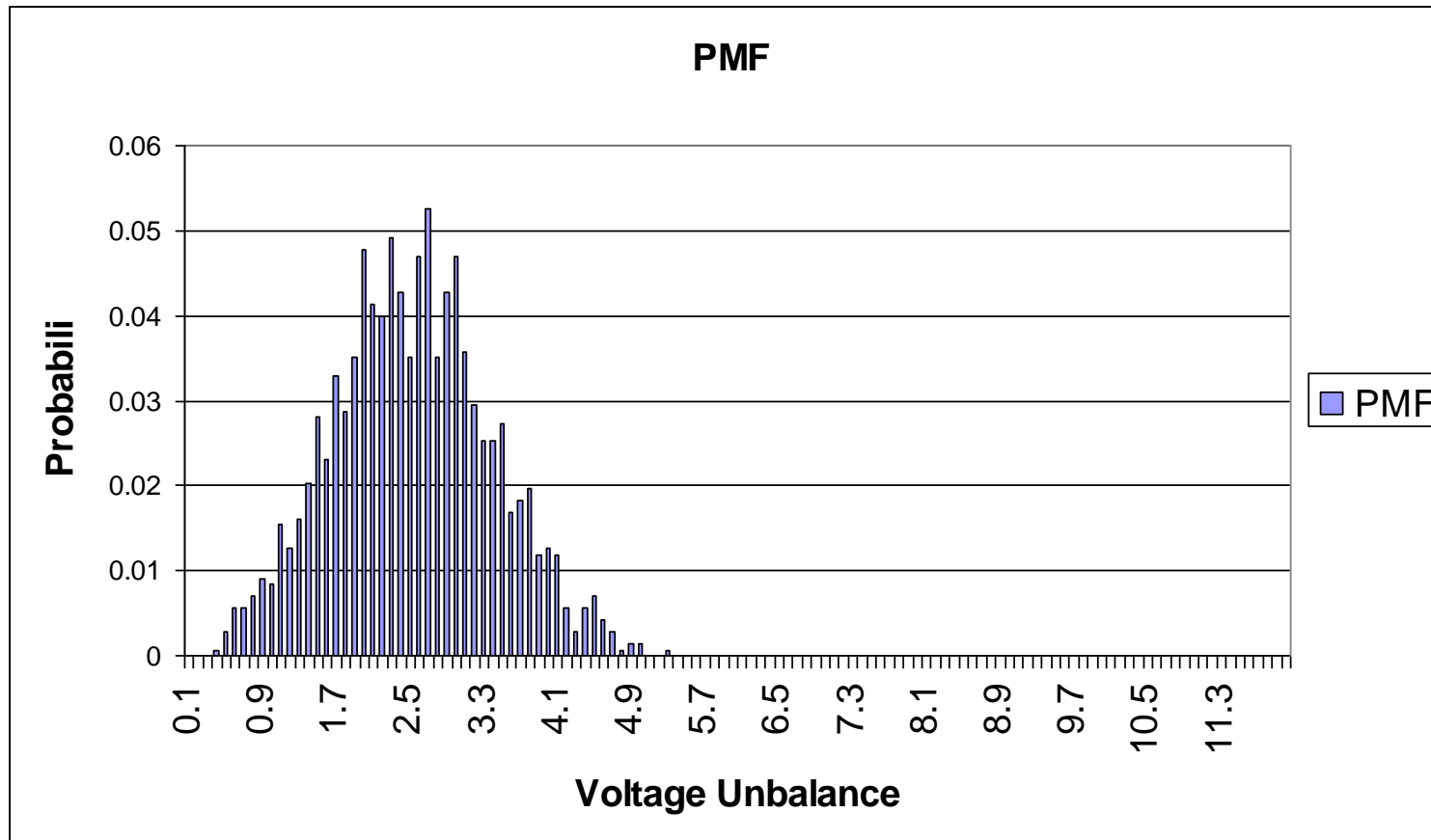
ReticObject.Calc

End If

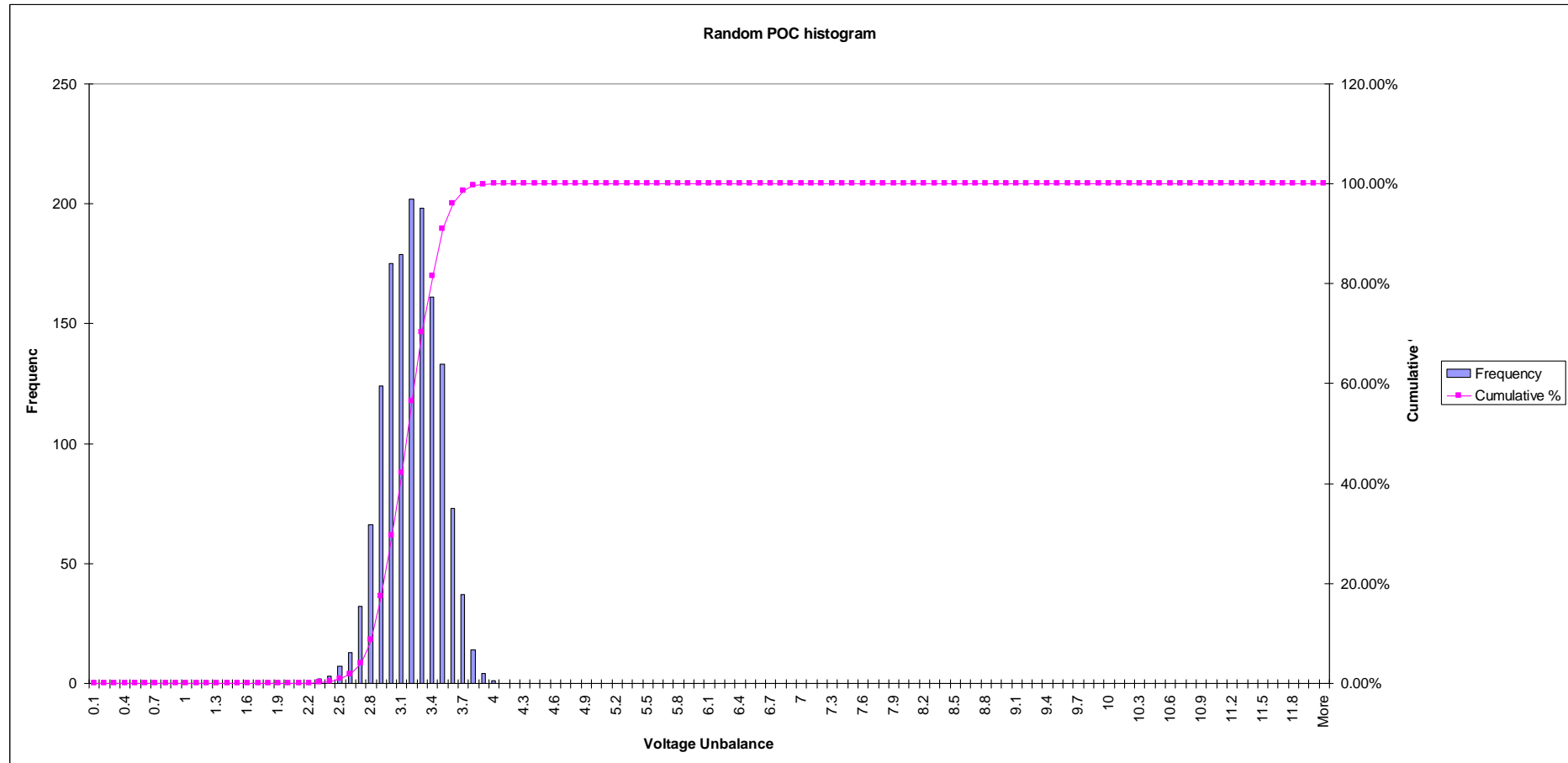
End Sub

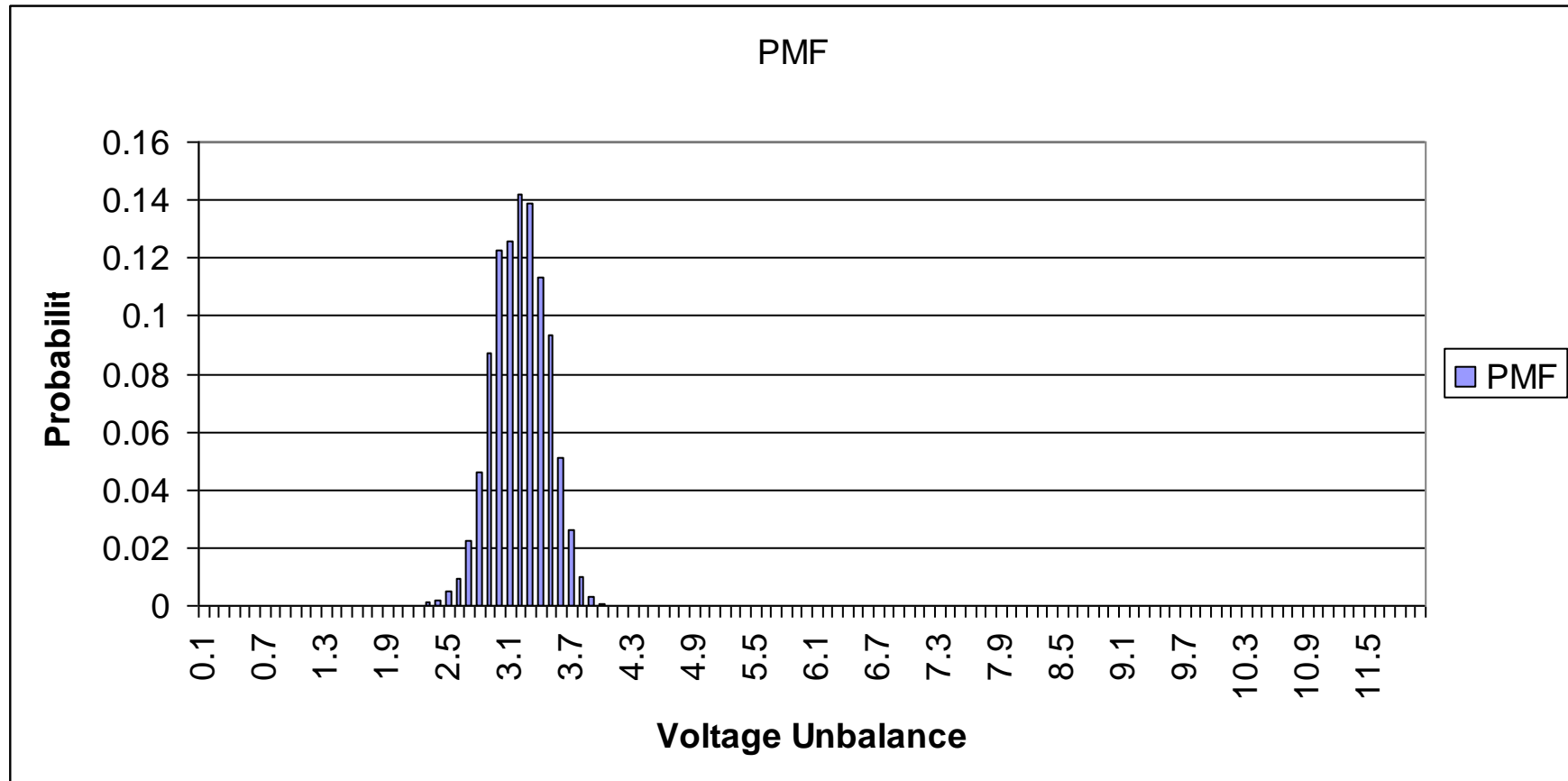
Appendix C – Histograms results for the random connection study

C1: Random Load results

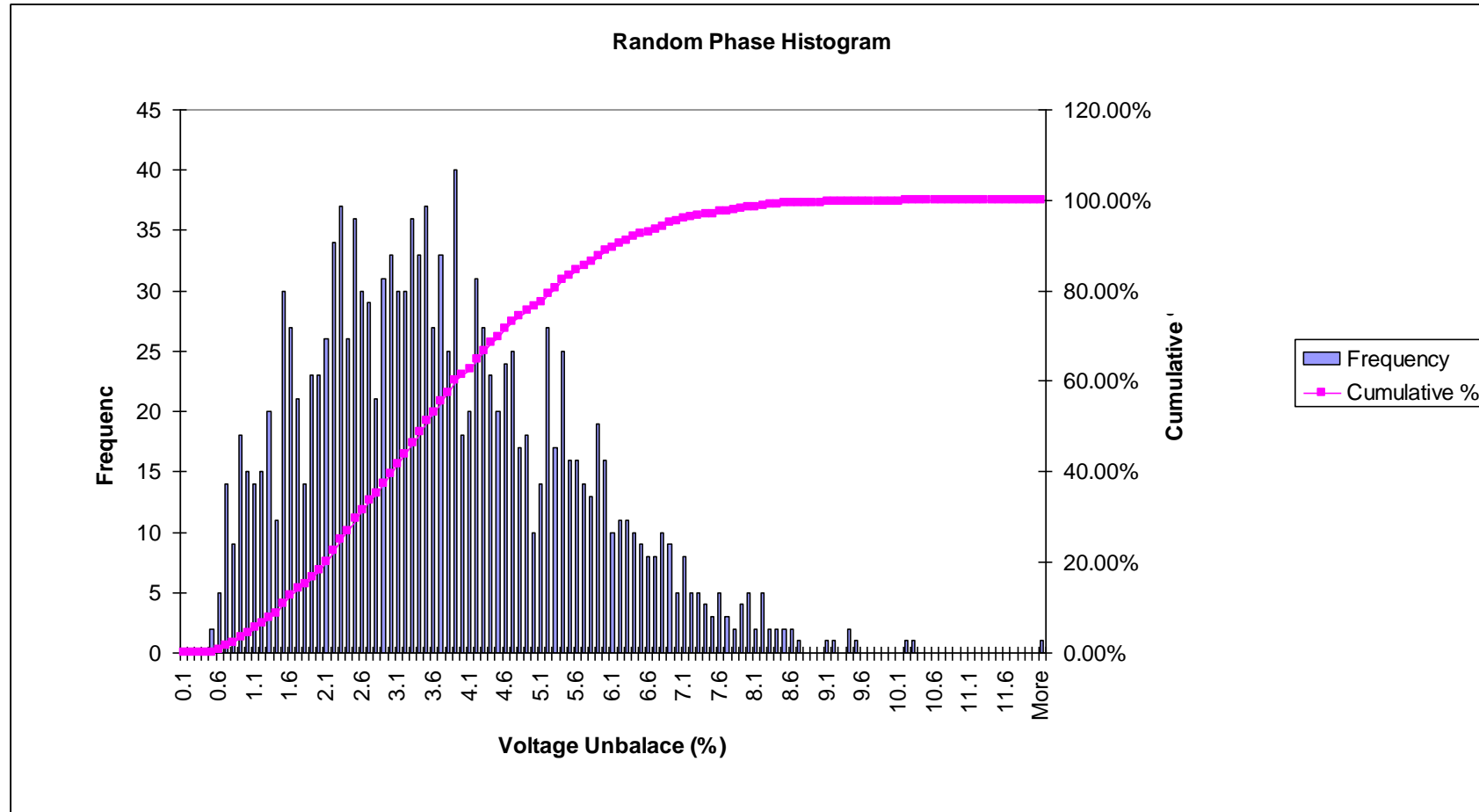


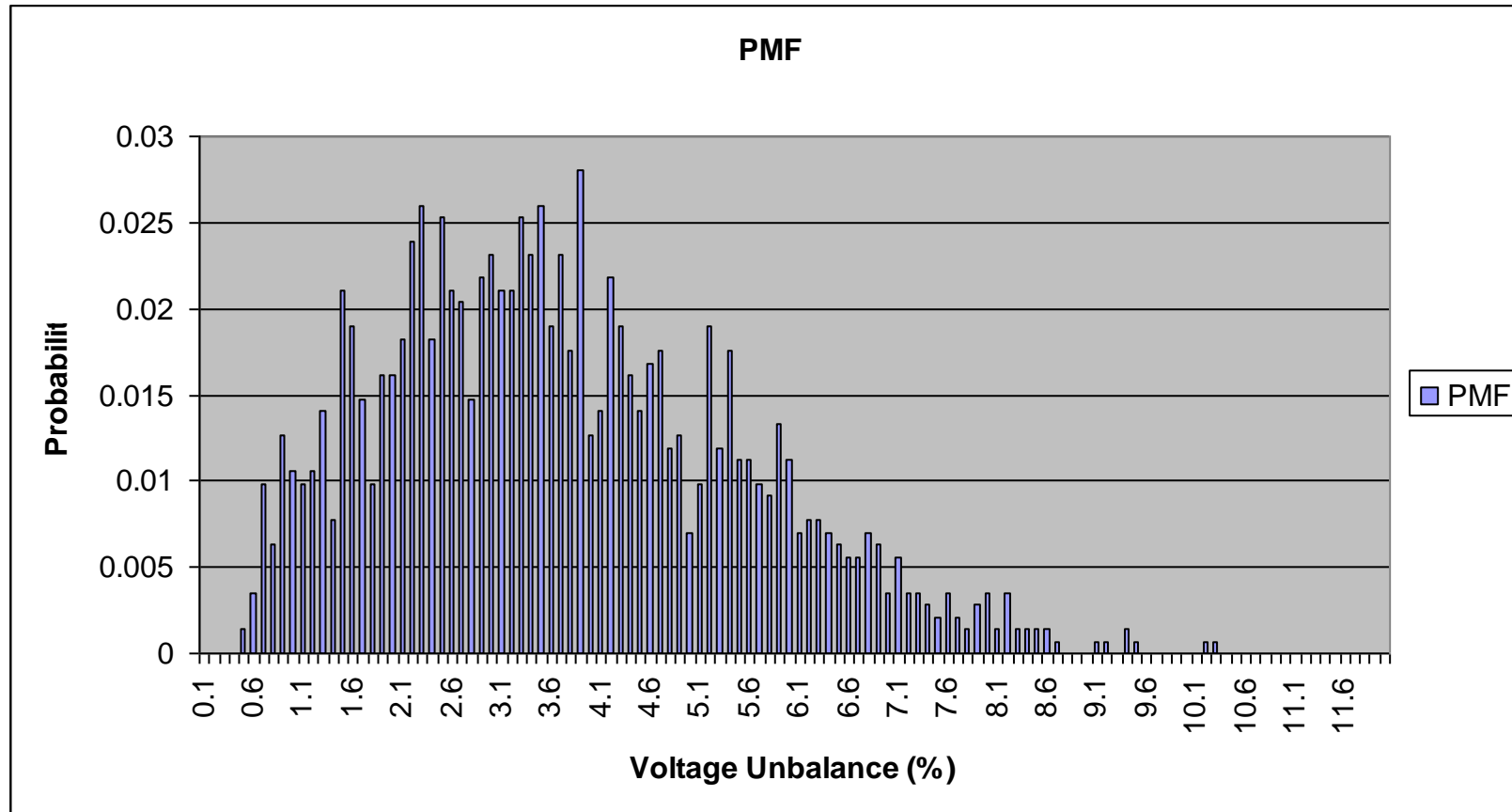
C2: Random POC results



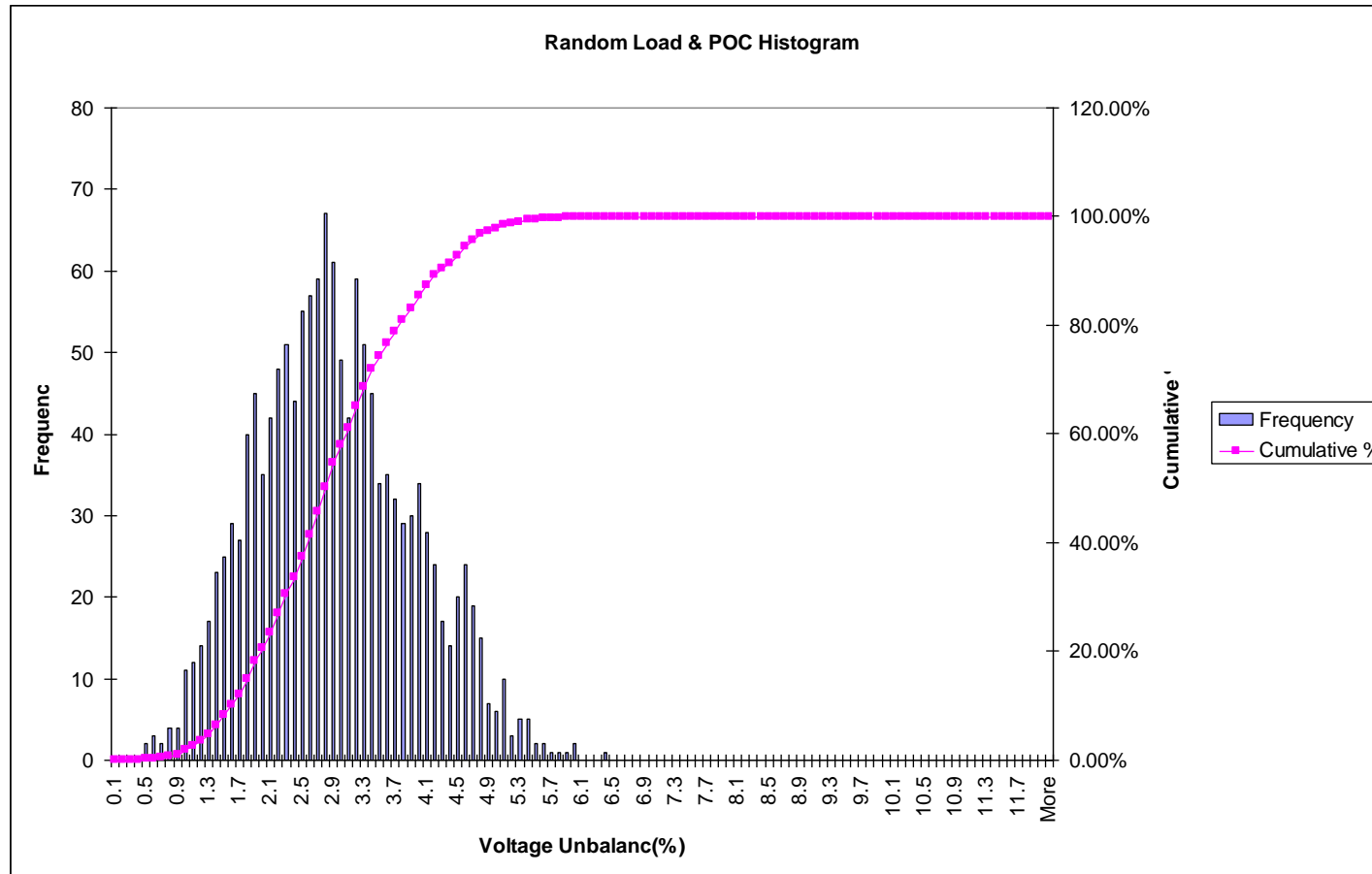


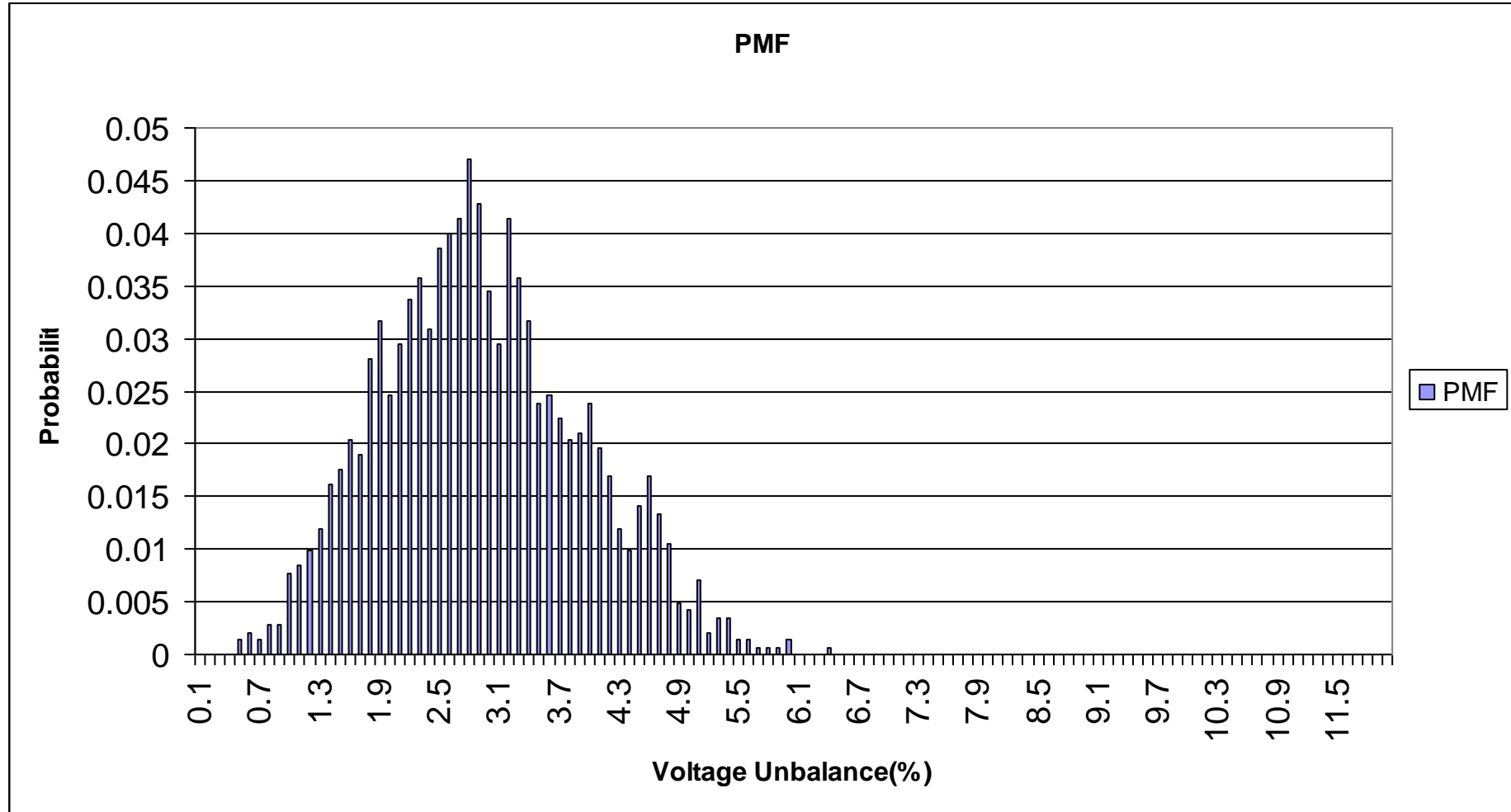
C3: Random Phase results



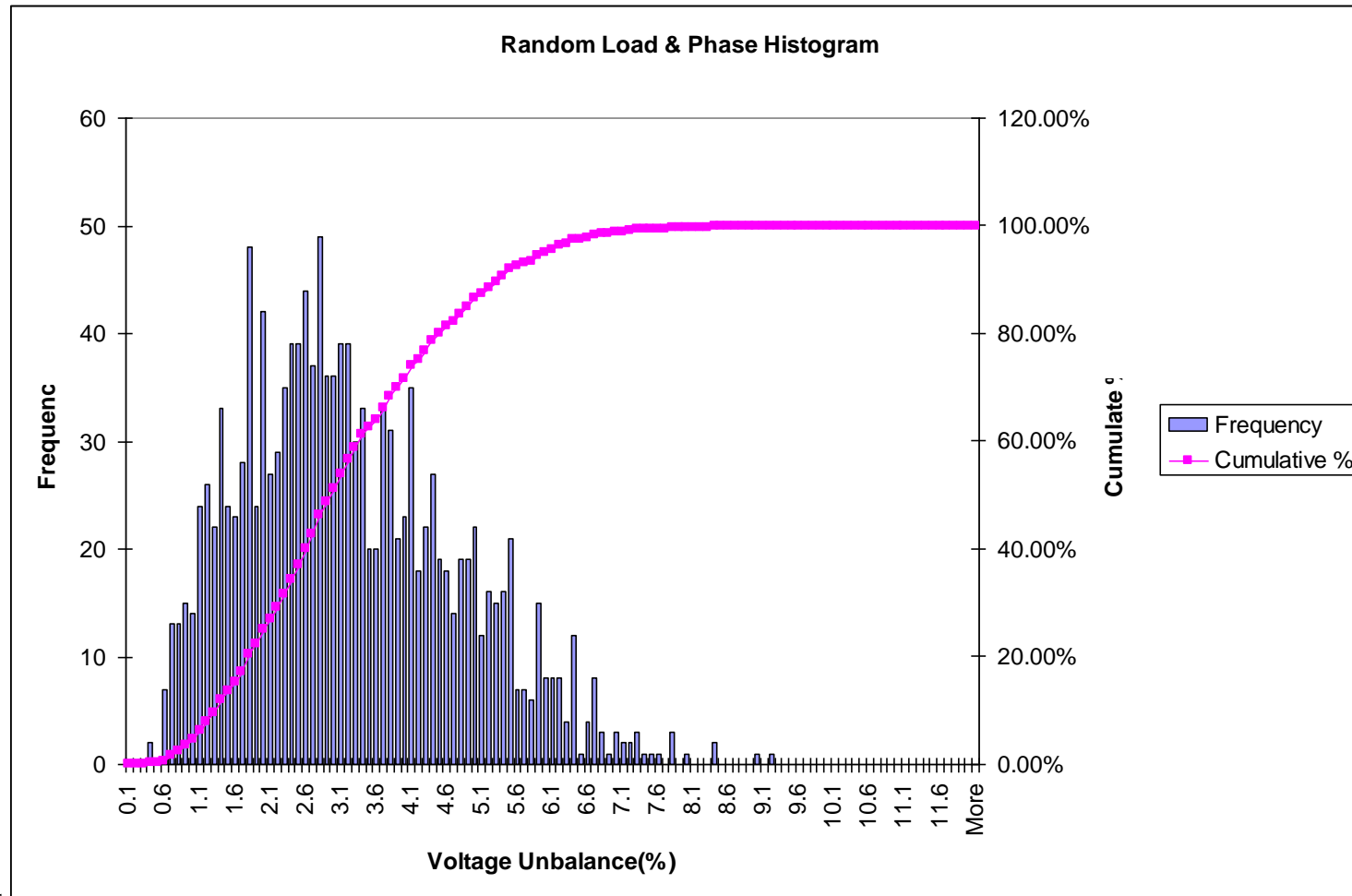


C4: Random Load and POC results

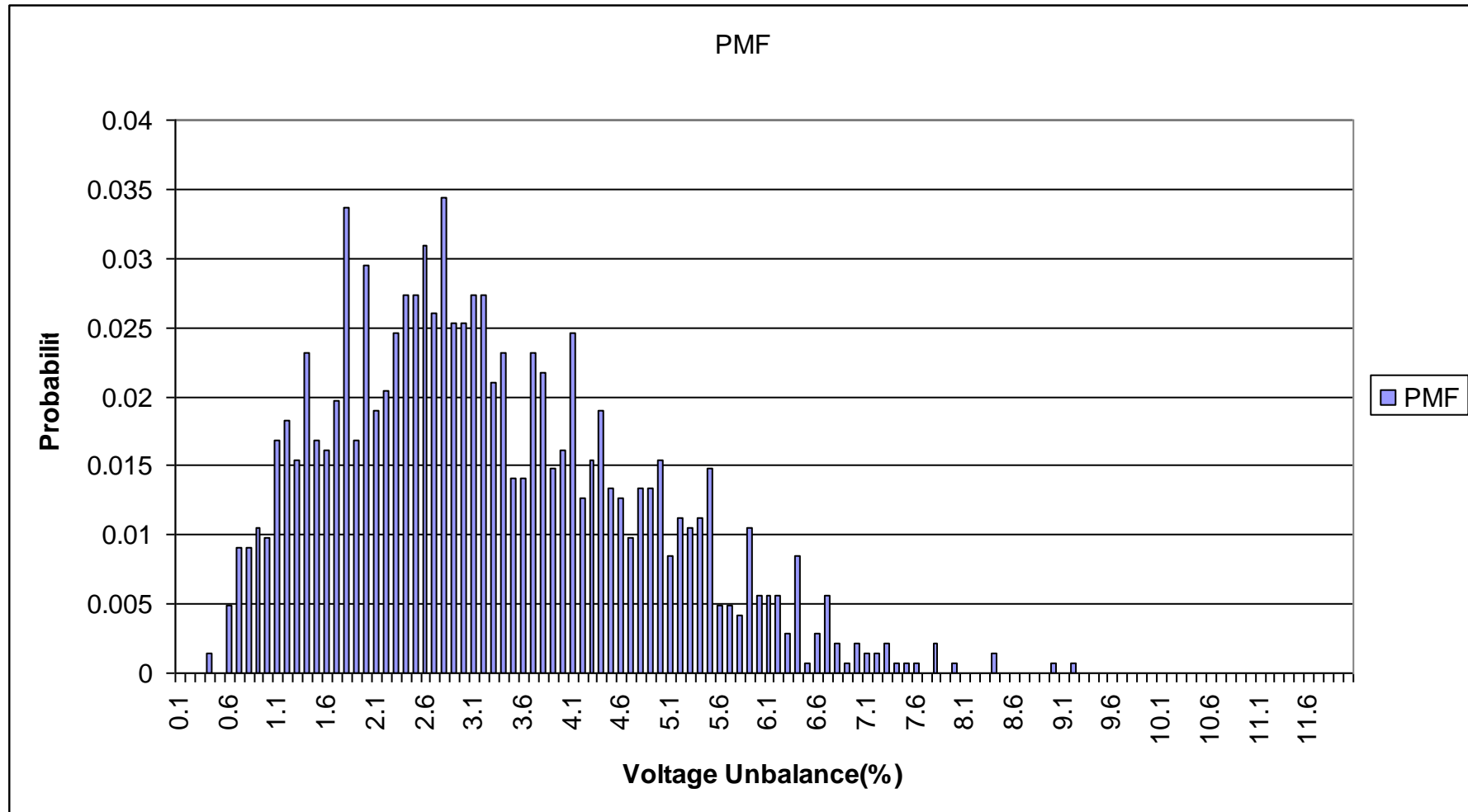




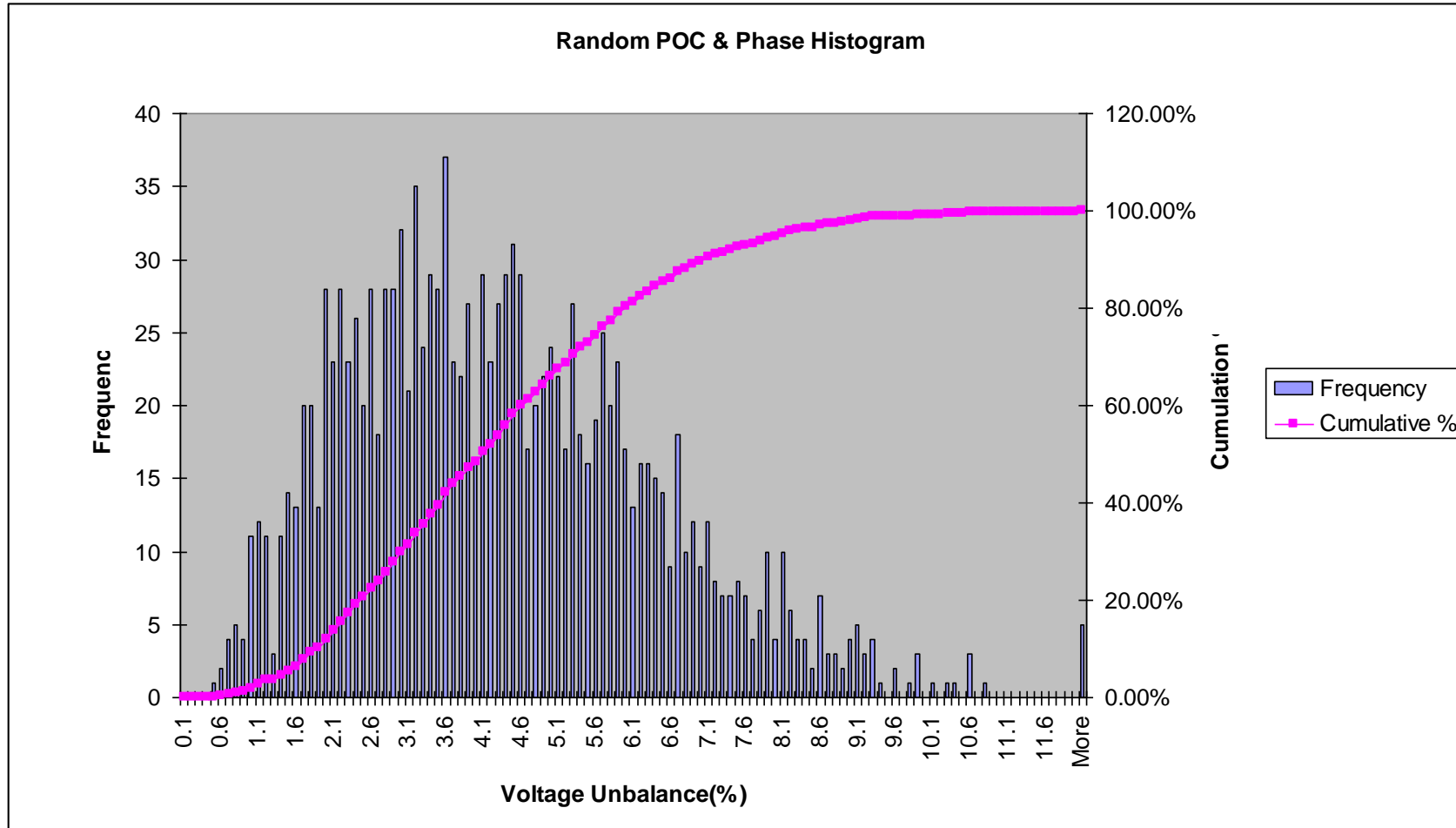
C5: Random Load and Phase

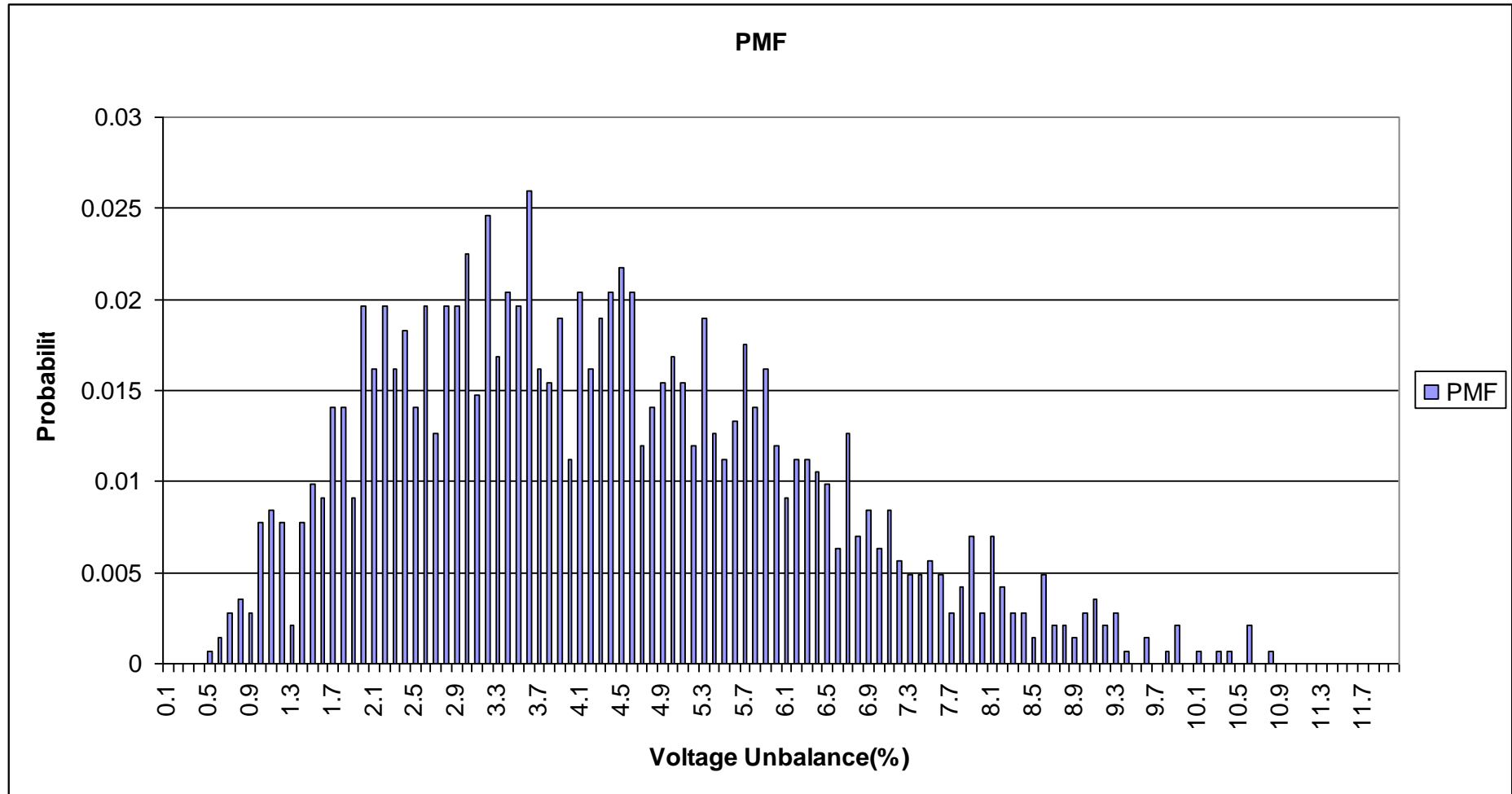


results

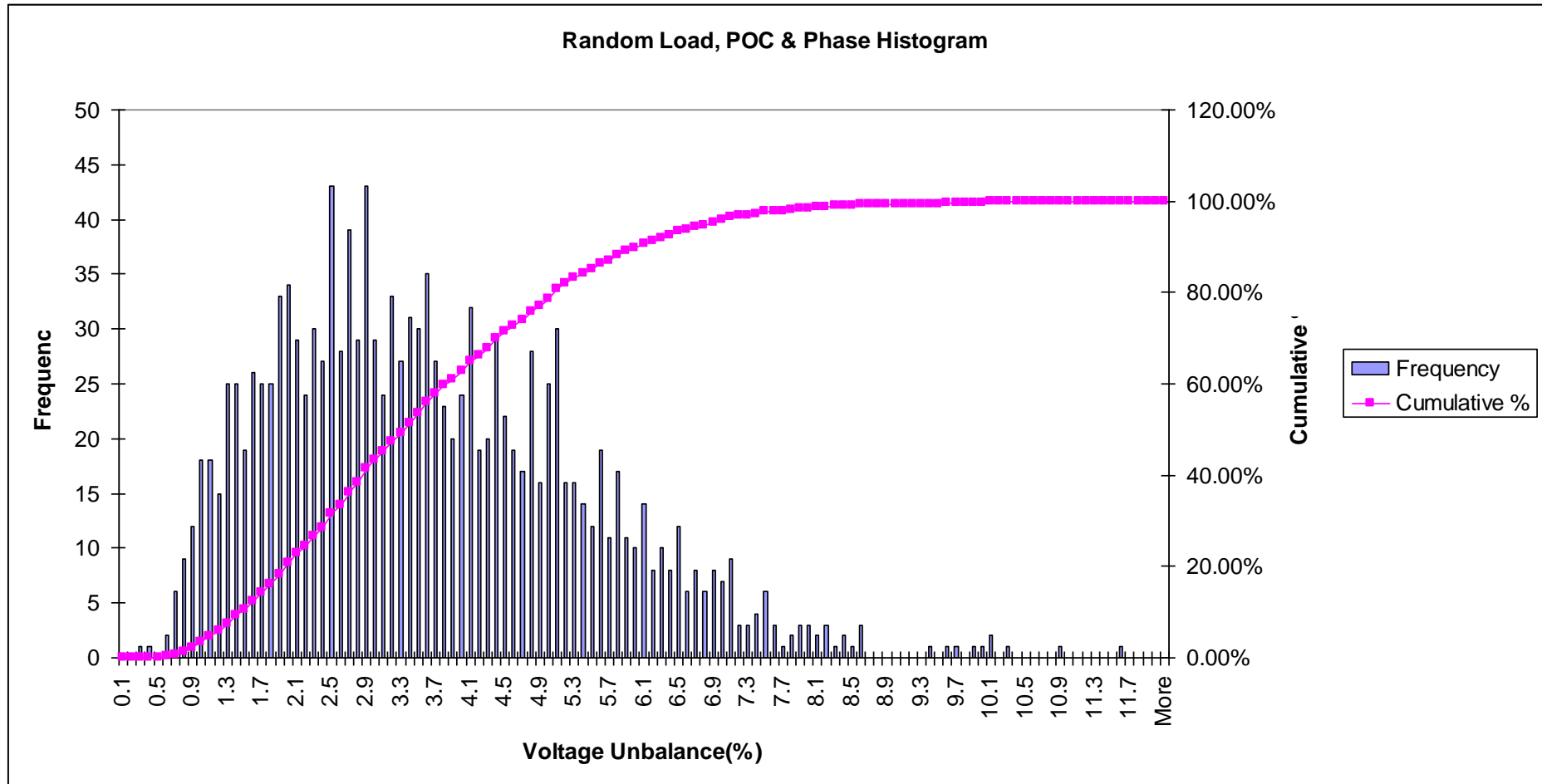


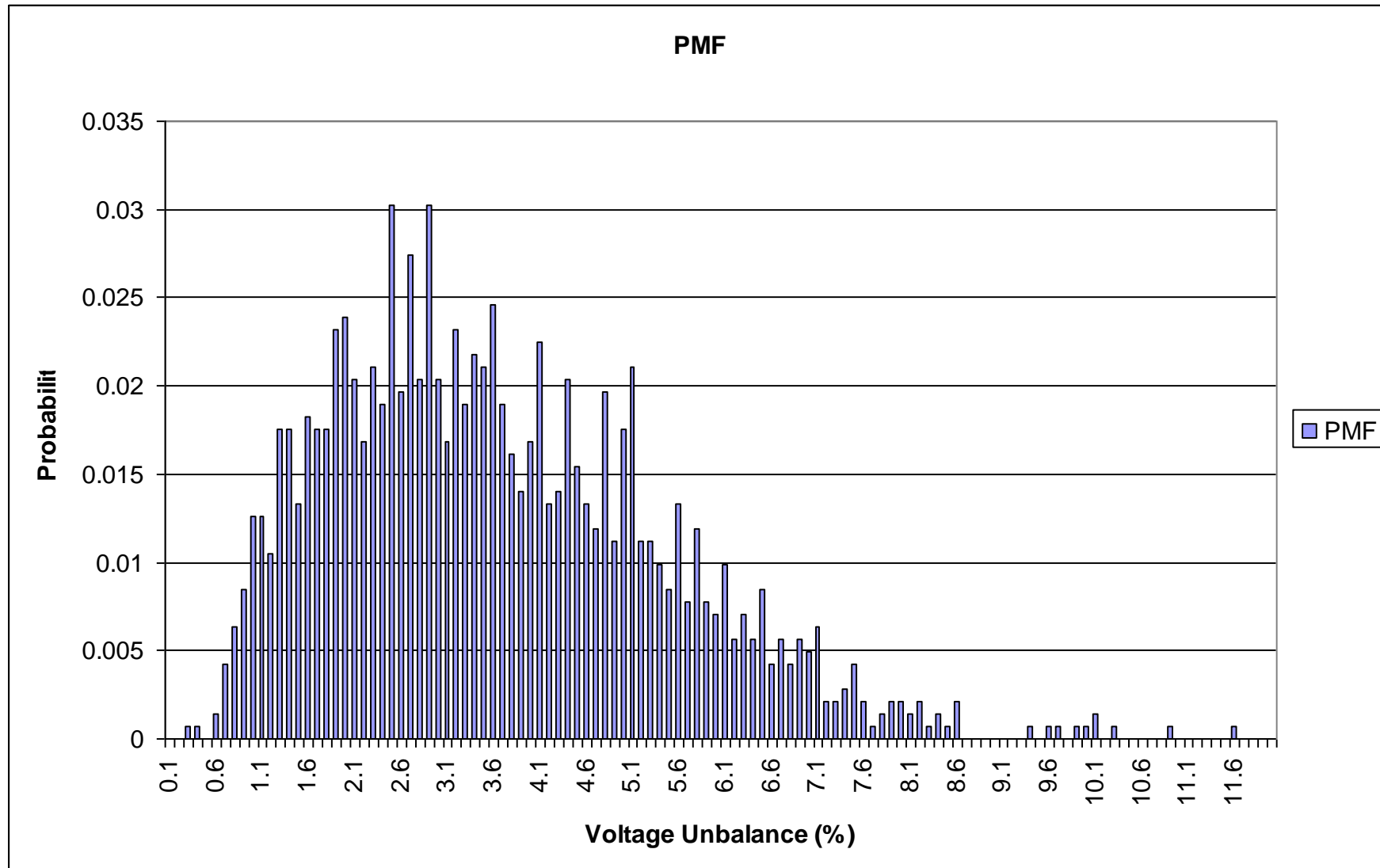
C6: Random POC and Phase results



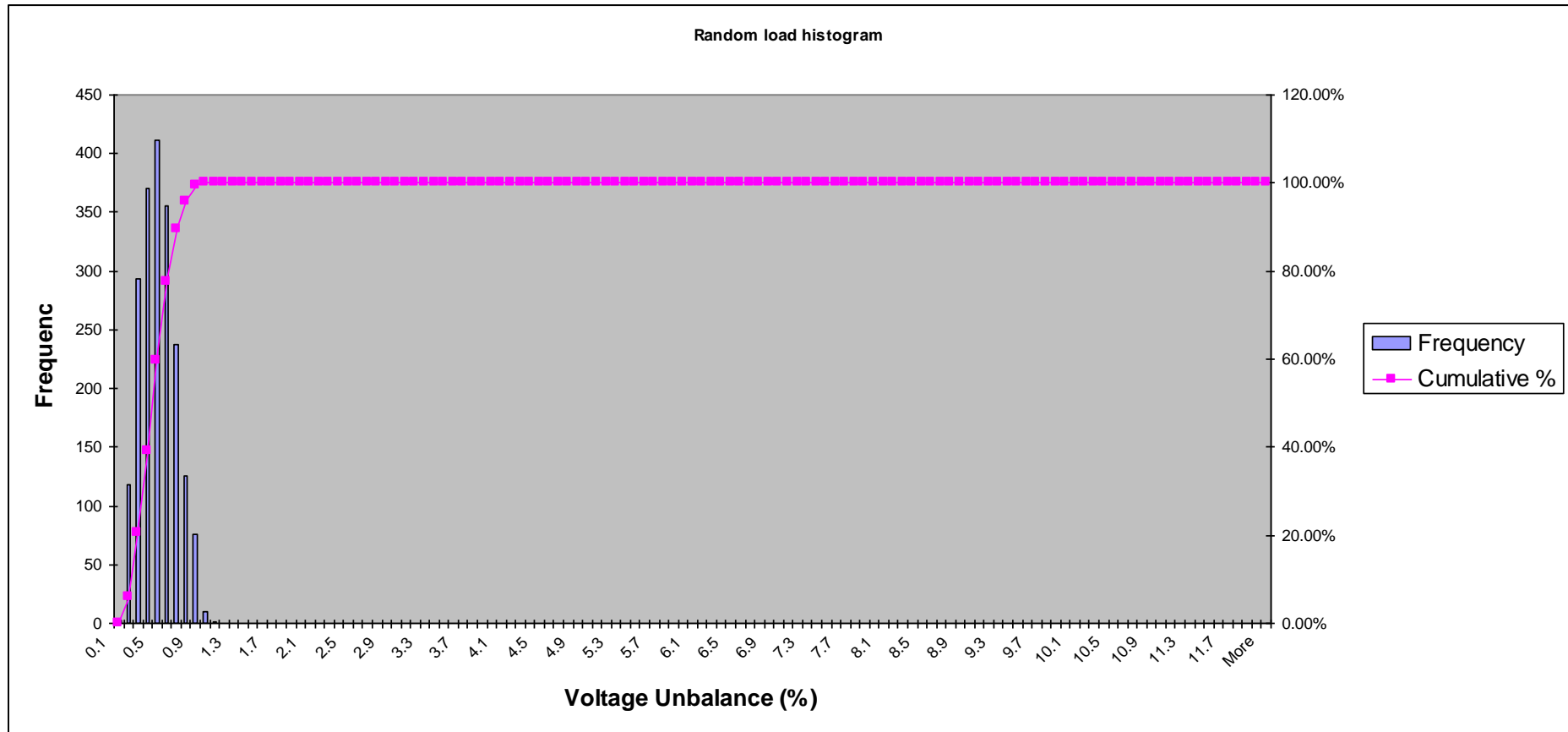


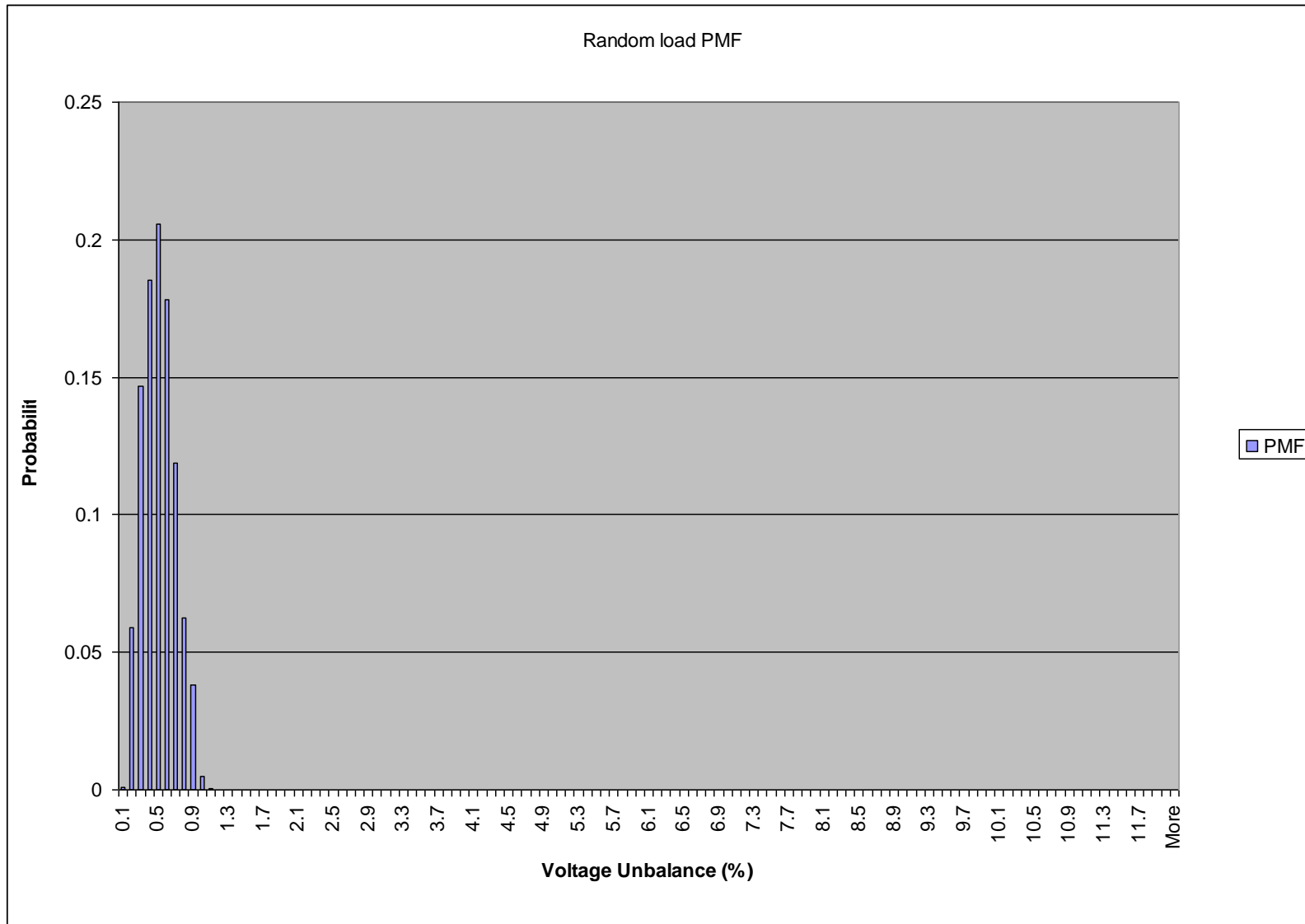
C7: Random Load, POC and Phase results



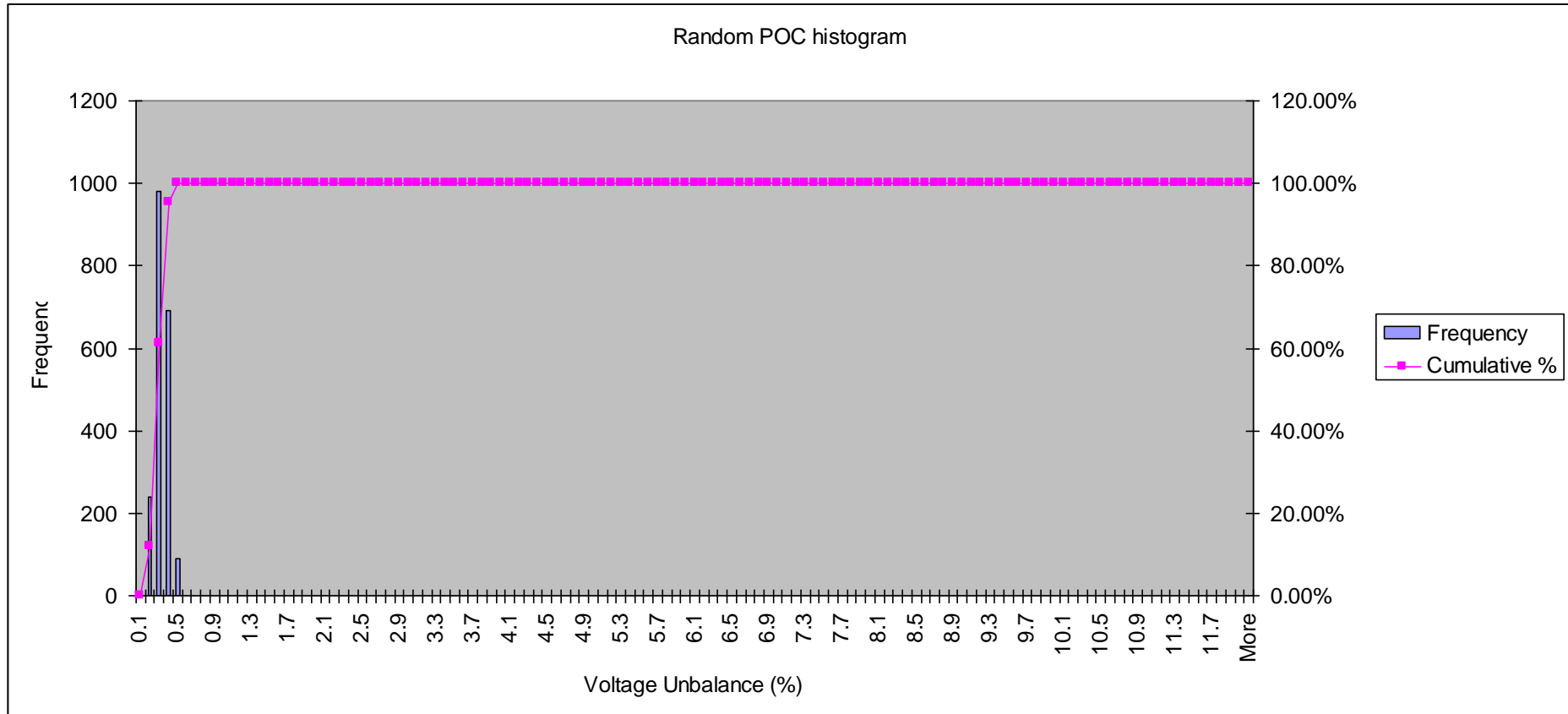


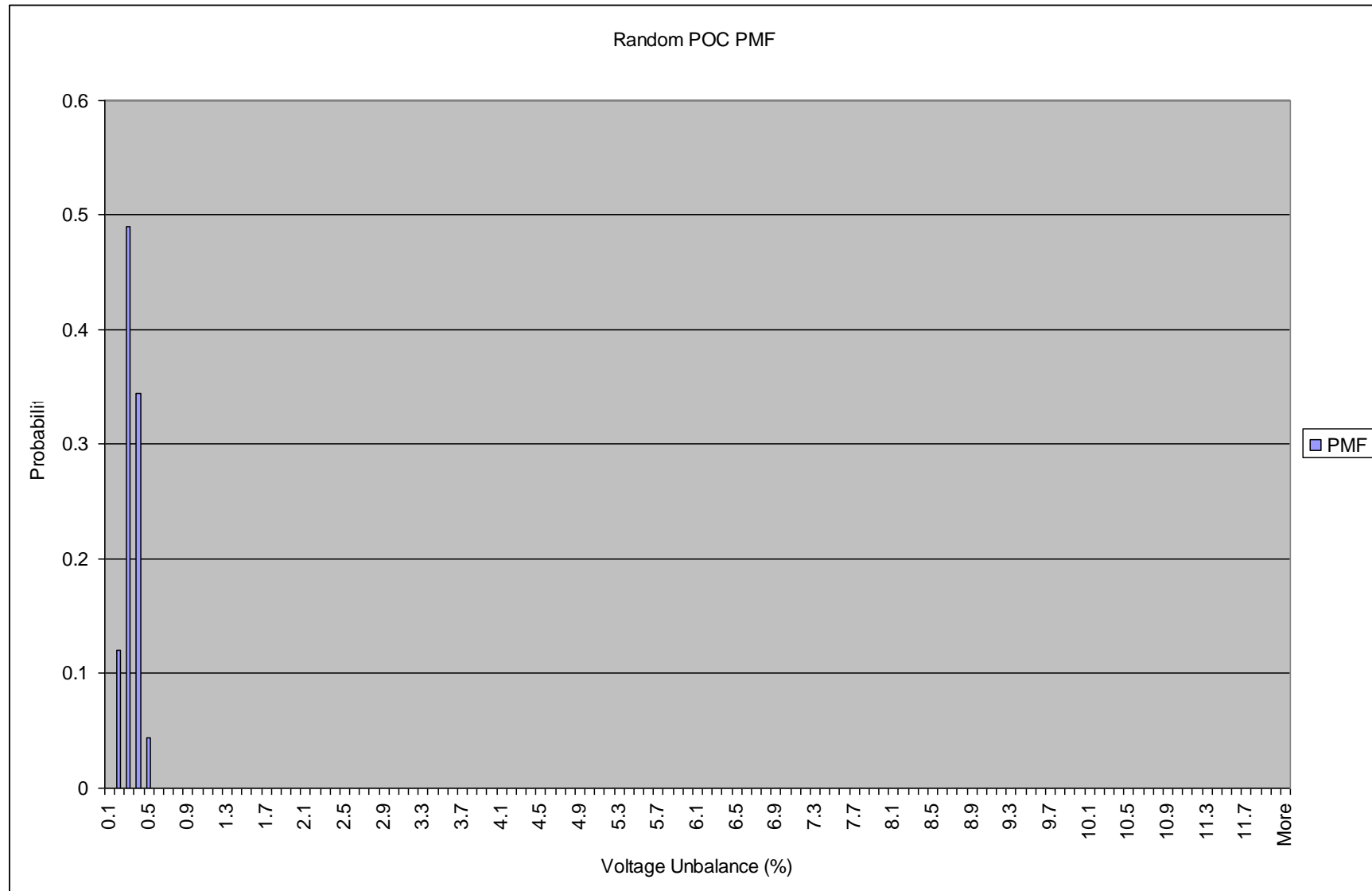
C8: Random Load results



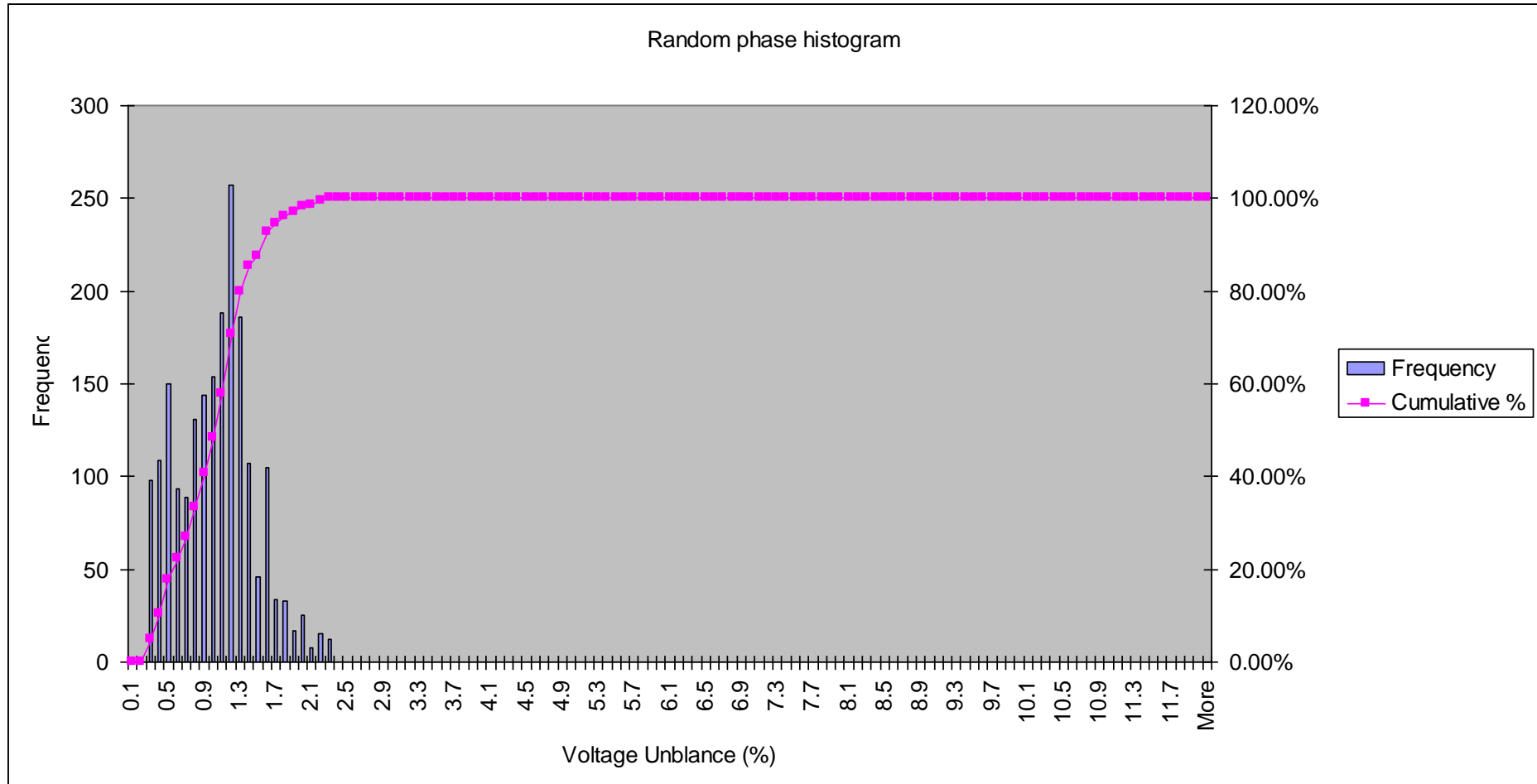


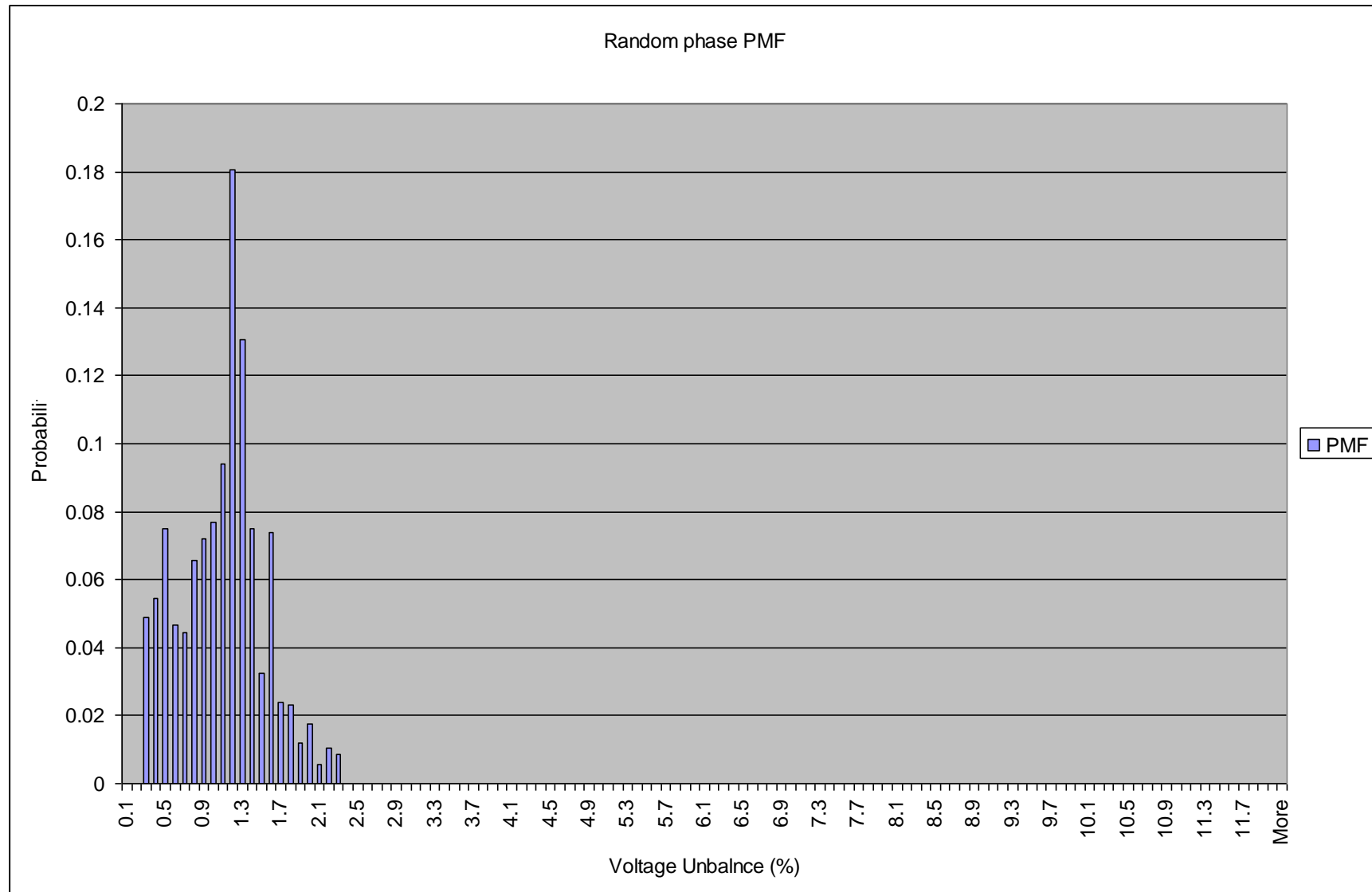
C9: Random POC results



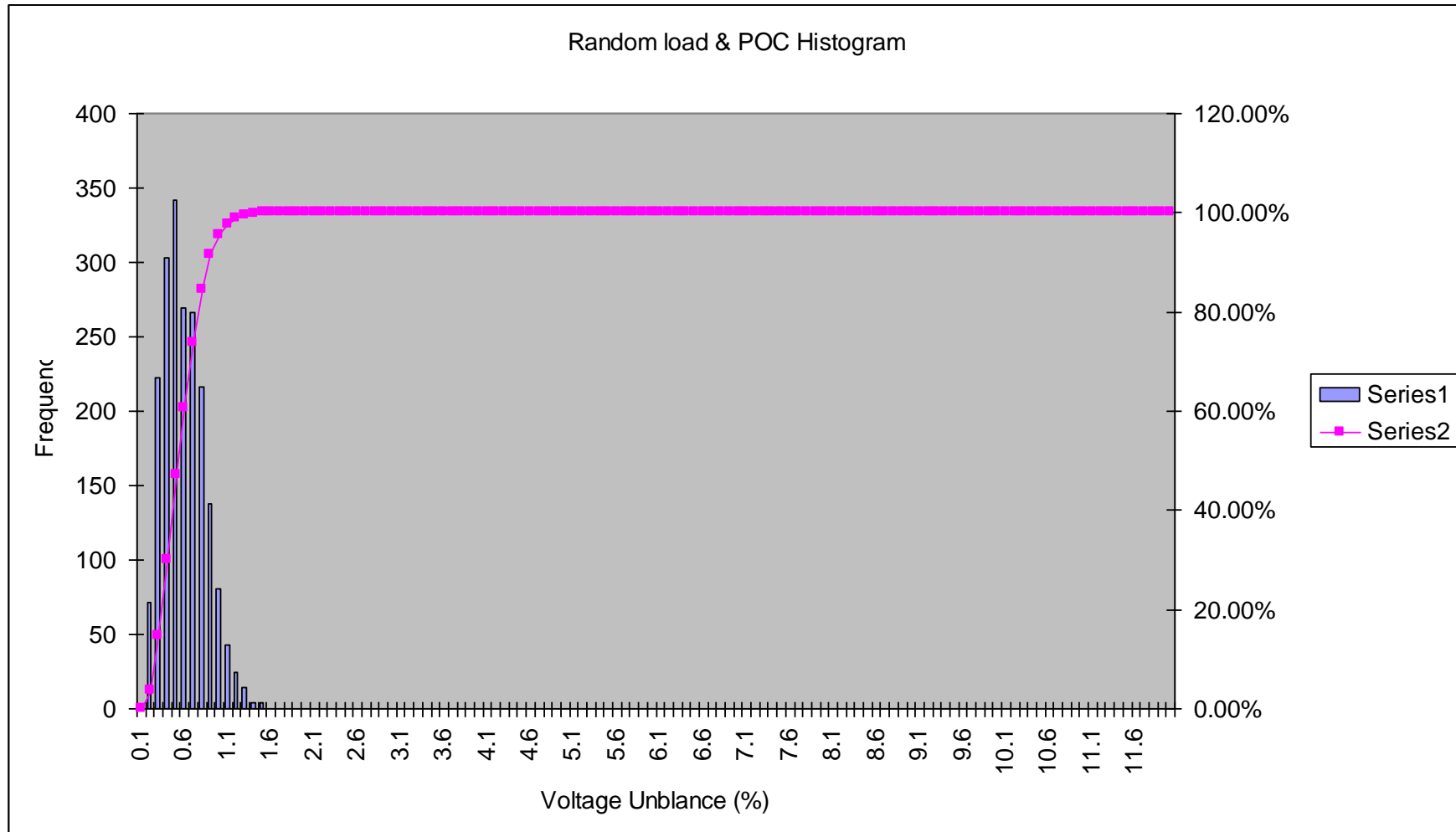


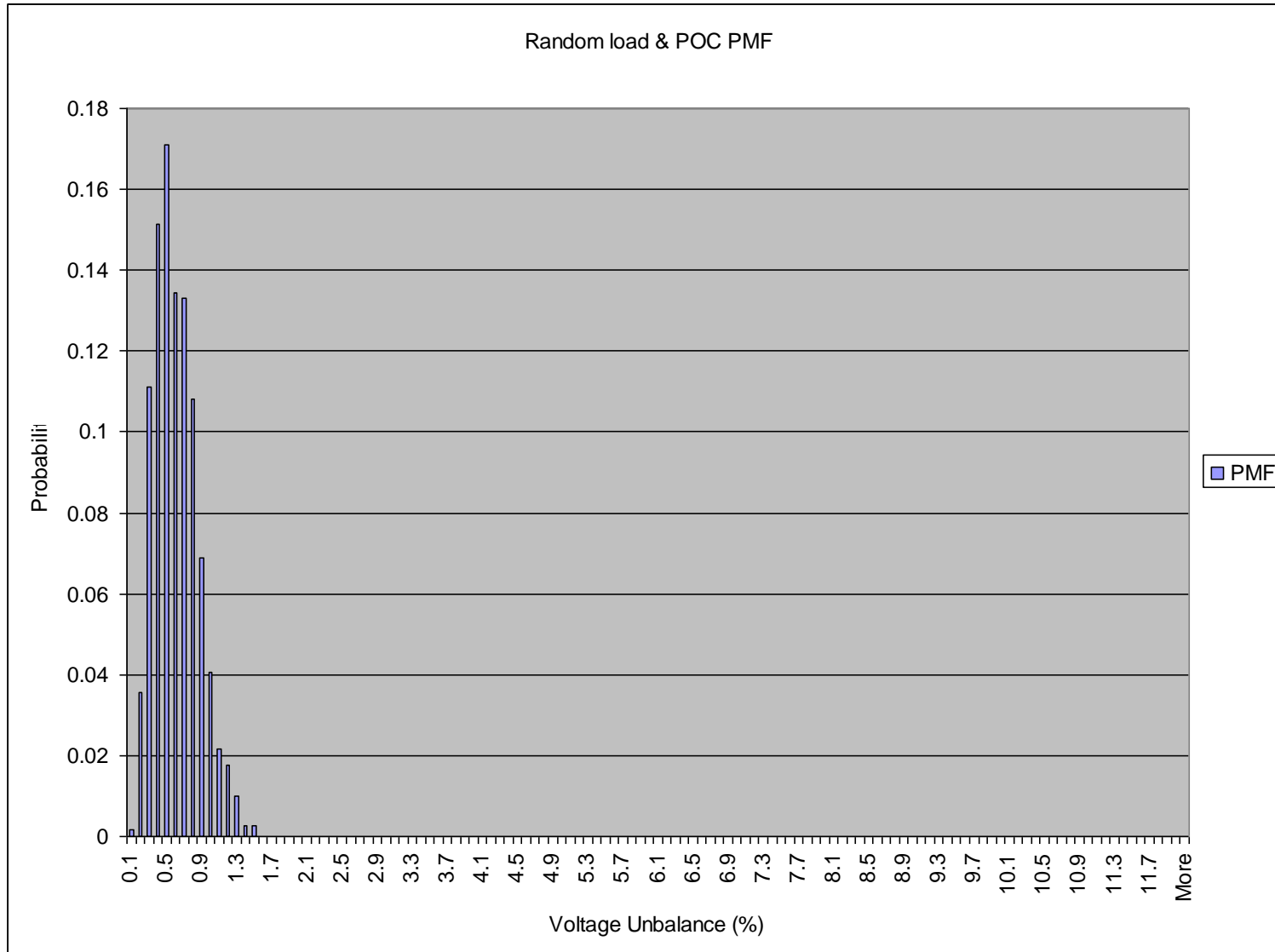
C10: Random Phase results



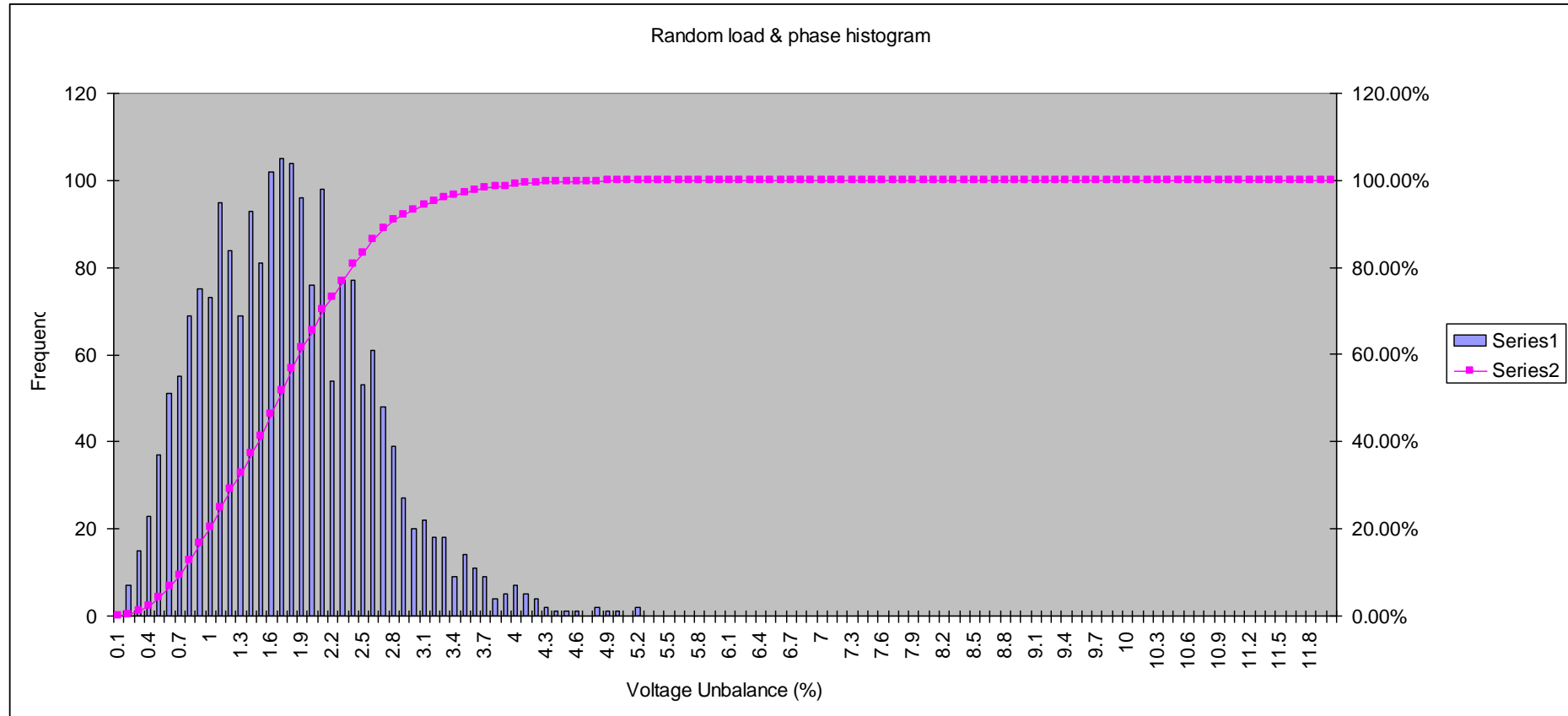


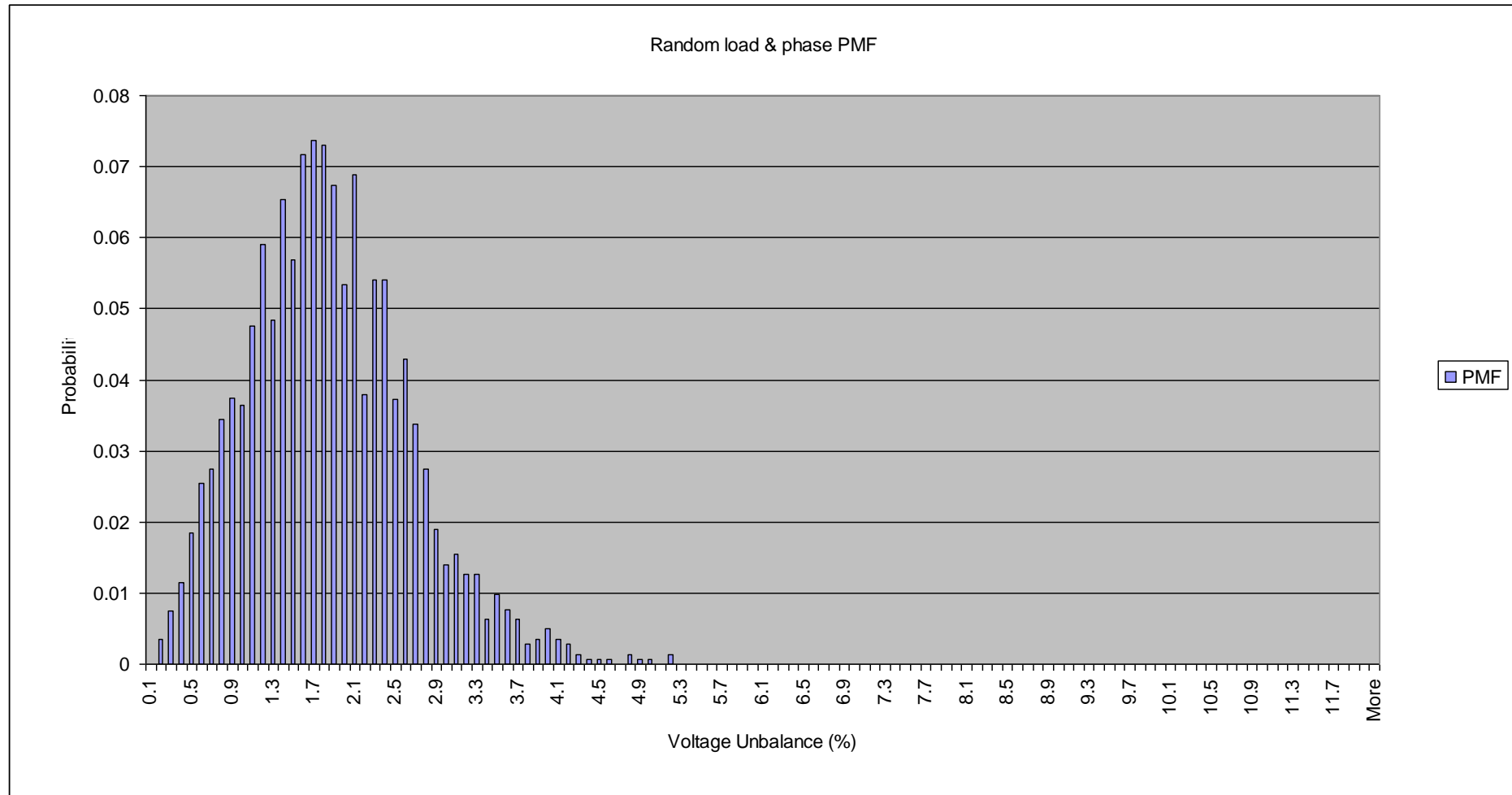
C11: Random Load and POC results



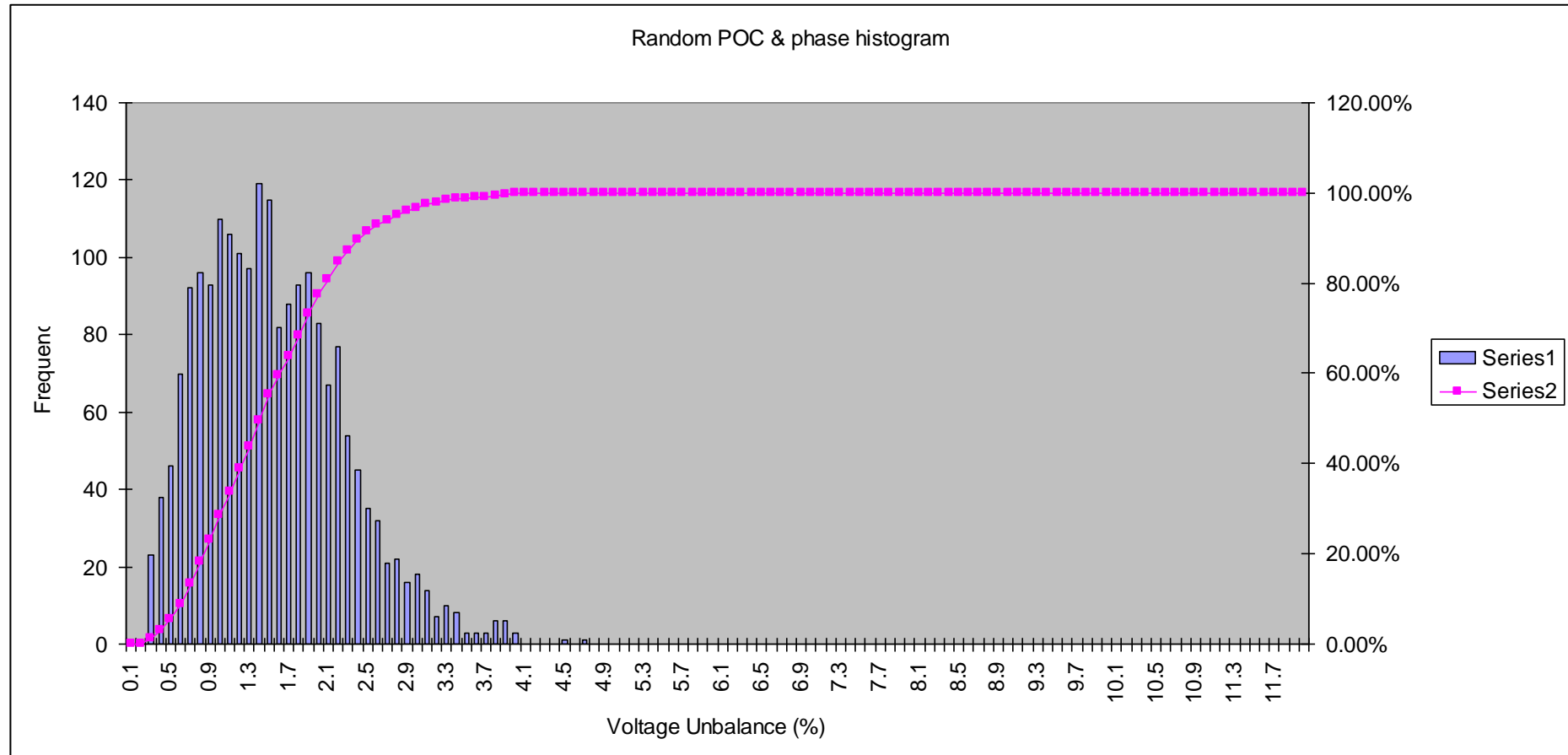


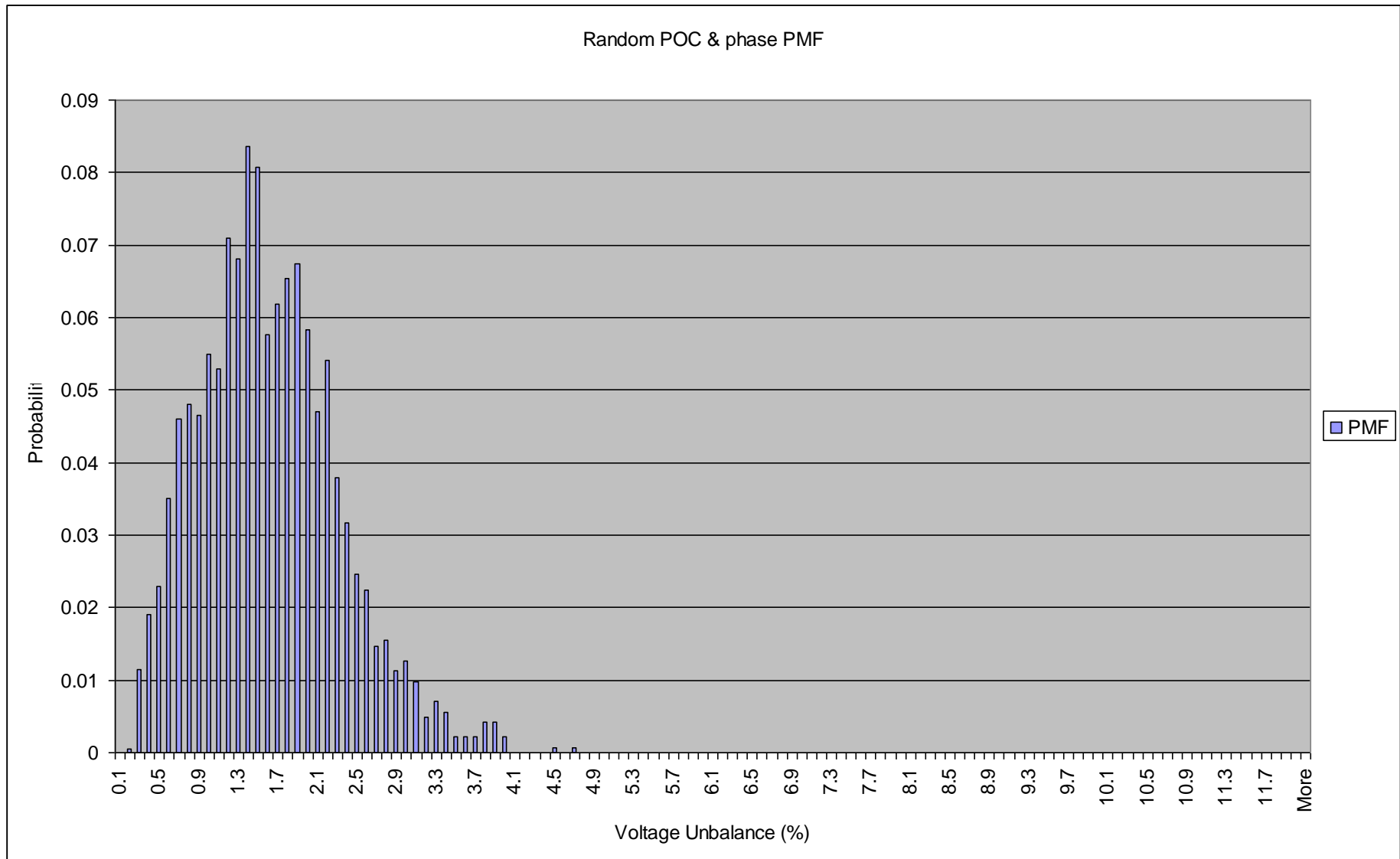
C12: Random Load and Phase results



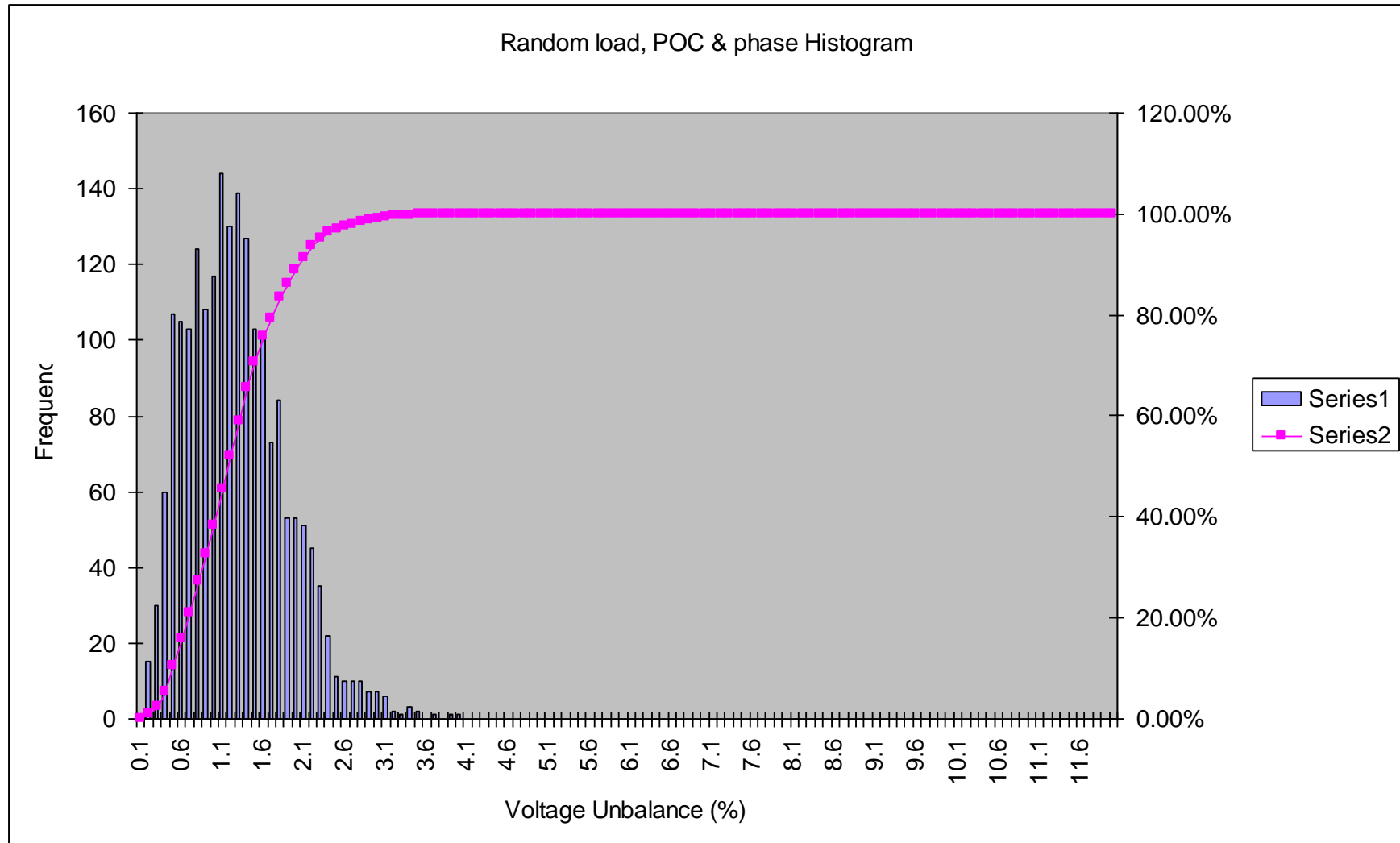


C13: Random POC and Phase results





C14: Random Load, POC and Phase



results

